BONE GRAFT SURGERY IN DISEASE, INJURY AND DEFORMITY

Wolff's Law in Nature

The contours of the average tree depend almost exclusively upon the stresses that come upon its various component parts, so that the trunk where it leaves the ground has the largest diameter and is the strongest part of the tree. The trunk tapers as it goes upward in proportion to the decrease in weight and wind force The same is true of the branches They are larger at the junction with the trunk and taper off as the stress decreases. However, in the case of the banyan tree where lanai illustrated at *H* grow and reach the ground as at *B* and *D*, either without help or aided by tubes filled with earth, support is provided for the distal part of the branch The metamorphosis of the branch is most striking and the usual contours of the limb become reversed so that the diameter at *A* exceeds that at *C* which in turn, surpasses *E*. It is interesting to note that this phenomenon is equally well illustrated in the animal kingdom by the increase of diameters of a bone graft in response to the function of stress in accordance with Wolff's law. (See frontispiece, opposite, showing banyan tree developed by author in Florida.)

BONE GRAFT SURGERY IN DISEASE, INJURY AND DEFORMITY

BY

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INCORPORATED

NEW YORK LONDON

Acknowledgment is made to W. B. Saunders Company and Paul B Hoeber, Inc., for permission to use material from previously published works by the author, namely, *Bone Graft Surgery, Orthopedic and Reconstruction Surgery*, and *Injuries and Diseases of the Hip.*

PRINTED IN THE UNITED STATES OF AMERICA

DEDICATED
TO THE PROGRESS OF
BONE AND JOINT SURGERY

PREFACE

It is now over twenty five years since I set myself to the task of writing the first book published in any language upon the sole subject of bone graft surgery Since that time the trustworthiness of such work has been amply proven Bone graft operations were then relatively new, but have since been adopted by the surgical profession the world over, much to the benefit of the patient

In the present volume there are incorporated those procedures which have stood the test of time namely those which I have used myself, and those which I have not elected to use myself but have included because of their employment by experienced surgeons of mature judgment

My original technic of bone transplantation although fundamentally unaltered since the early days of its inception is being utilized today in an ever increasing variety of ways for derangements of the bones and joints The reparative influence of the bone graft enables the reconstruction surgeon to keep pace with the unfortunate sequelae of industrial and road accidents The therapy of congenital absence of such bones as the radius tibia and fibula as well as congenital nonunion can now be undertaken with greater assurance than was possible heretofore The Albee bone graft spine fusion operation has rendered the treatment of a wide variety of affections of the spine including Pott s disease vertebral fractures scoliosis spondylolisthesis and diseases of the sacro iliac joint less formidable

The bone graft peg is believed to be the ultimate solution as primary treatment of those cases of central fracture of the neck of the femur when the ligamentum teres has been ruptured at the time of fracture a very frequent occurrence The autogenous peg is also the method of choice in nonunion of the hip and if the degree of femoral neck absorption is prohibitive to the use of the peg then the removed femoral head modeled to a wedge serves to reconstruct the hip The author in 1908 was the first to offer an operation for arthrodesis of advanced osteoarthritis (senile coxitis) and other conditions In fact the bone graft is an important feature in procedures for ankylosing all joints for a multitude of conditions

Resection of malignant bone tumors and immediate restoration of the involved portion of the skeleton by transplanted bone have marked a new achievement for the bone surgeon In fact the author s statistics

show that although limbs are saved by such methods, still the risk to life is no greater than when the limb is sacrificed by amputation. The ravages of poliomyelitis have been tempered by the judicious application of arthrodesis and bone block operations. The limitations of tendon transplantation are becoming more clearly defined and more reliable when associated with stabilization operations upon the skeleton. My most recent contribution in this field is concerned with the paralytic hip, for which I have devised a method to elongate the kinesiologic lever at the top of the femur for the purpose of obtaining a more stable hip and a stronger weight-bearing limb. This operation has also been found to be effective in a number of other conditions where the lever has been shortened, namely, in epiphysitis, destruction from tuberculosis, congenital dislocation, insufficiency of the trochanter following arthroplasty, and nonunion of the hip with absorption of the femoral neck.

One might make the query—are there any outstanding reasons for the development of so vast a realm of surgery in such a short space of time? The principal reasons for this, I believe, are the development of the x-ray, the bone mill, the orthopedic traction operating table, and not least, the proof of the wonderful dependability of autogenous bone transferred from one part of the body to another. In a few words, these thirty years of continued pioneer advancement have largely revolved around the various applications of the transplantation of living tissue of which the following are most important: bone, cartilage, tendon, muscle, fascia, subcutaneous tissue and the skin. The development of surgical armamentarium for cutting and modeling hard bone which at least approaches that of the power driven precision tools of the machinist or cabinet maker has played a most important rôle.

Acknowledgment must be made of my obligation to the profession the world over for the kindness and consideration with which they have during the past thirty years, accepted and put into use the various original uses of the bone graft which as a pioneer, I have suggested from time to time during the whole period.

FRED H. ALBEE

FOREWORD

Dr Albee's first work on bone graft surgery was written in 1915 Prior to that time, he had assisted Dr Henry Ling Taylor in writing a substantial work upon the broader subject of orthopedic surgery in general At the time when Dr Albee wrote his book in 1915, his accomplishments in the field of bone graft surgery were already very considerable During a few years preceding since 1911 he had published many articles on the subject, including some in French Spanish and German The possibilities of bone graft surgery, as well as the appeal of its very interesting technic, had already captured the imagination of the surgical profession To orthopedic surgeons especially it opened up a field on the operative side in which not many surgeons had previously been engaged

It is not too much to say that the entire specialty has been broadened and elevated by the addition of this kind of work The new interest of surgeons generally in other phases of orthopedics apart from the purely operative side has also enabled all of us to make much out of Dr Albee's contribution The effect of the Albee bone graft methods in preventing and correcting deformity and in the alleviation of disability is not even now fully appreciated Nor are these methods employed by surgeons generally for as many of their cases as we think they should be

Mechanical methods for the prevention and control of deformity, and for the relief of disability had already enabled orthopedic surgeons, even of the old school to do much for their patients But with the adoption of surgical operative methods and especially with the methods and example of Dr Albee they have been able to work with greater satisfaction to themselves, as well as to obtain better results for their patients, than would ever have been possible otherwise

That there have been improvements in technic and many alterations in the exact procedures suggested by Dr Albee in his first book is greatly to the credit of his own efforts His original contribution, not only of technical methods, but of the electrically driven surgical apparatus (the bone mill) which he proposed has rendered all of such work easier and more satisfactory, more precise and more efficient As Dr Albee has improved his technical methods and widened the field of bone graft surgery and even as he has improved his apparatus he has carried all the rest of us along with him to better work in wider fields and to greater

achievement than any one could have dreamed of in the first years of his proposed bone graft operations.

In Dr. Albee's original work in 1915, much more attention is paid to fundamentals and to principles and a much more thorough study made of those who had worked in this field prior to Dr. Albee's time, than he is generally given credit for. The original experiments of Macewen, Ollier and other British and Continental surgeons are not only studied, but the principles and methods which they proposed are duly credited to them. His own extensive animal experimentation served to establish a sound bio-physiological basis for his method of bone grafting. This work was done while Professor of Orthopedic Surgery at Cornell University. Portions of bones of dogs were transplanted to the sheep and *vice versa* to demonstrate the physiological incompatibility of heterogenous bone grafting. That we have gone far ahead of any of their dreams is due more to the industry and devotion of Dr. Albee than to anyone else. That others have made contributions to technic and to apparatus may also be credited indirectly to him. The writer of this foreword is glad to acknowledge not only his own obligation, but the obligation of many of his patients to the instruction and example, as well as to the inspiration of Dr. Albee in this important field of the surgical prevention and cure of deformity, disability and bone and joint disease.

H. Winnett Orr, M.D., F.A.C.S.

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BONE GRAFT SURGERY IN DISEASE, INJURY AND DEFORMITY

CHAPTER I

THE GENERAL PRINCIPLES OF BONE GRAFTING

The principles of grafting living tissue are exemplified in their simplest form in plant grafting One can safely assume that the principles of plant grafting cannot be violated in the grafting of tissues of a higher form and that grafting of bone cannot be as readily carried out as grafting of vegetable material These postulates arise from the very nature of biological principles and decrease in adaptability with increase in specialization of tissue There are three inviolable rules in plant grafting the tissues must be applied like to like, the contact must be most intimate, and they must be immobilized in that position These principles are important but not as necessary in bone grafting In fact, there is a close biological parallel between wood and bone in that they are both supportive tissue, and although one is of the vegetable and the other of the animal kingdom they both present identical response to the laws of stress

Precisely as Sandow's bones increased in diameter, weight and strength because of the increased mechanical demands of stress coming to them from muscular development or the reverse influence from infantile paralysis, so does the living wood tissue respond to increased stress as is demonstrated in the frontispiece photograph of the banyan tree after the author had brought down to the ground by induced methods the aerial roots from the branch of the tree This living prop to the limb transferred the maximum local load of this limb from its junction with the trunk of the tree to just outside of its junction with the living prop and therefore, Wolff s law of stress determined that at that point the limb reached its maximum diameter and strength The bone graft responds in exactly the same way

When the bark and bud are removed from the scion, a piece of bark

of the same size and shape is removed from the host, so that like tissues of the scion will be applied to like tissues of the host in order that immobilization may be facilitated (Fig. 1). Interruption of the circulation of sap in the host is thus minimized. The "taking" of the graft

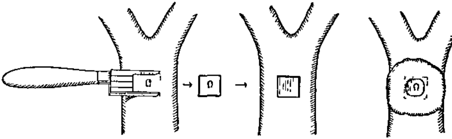


Fig. 1—Method of removing graft consisting of bud with portion of bark and alburnum and fixing it in a gutter in the host The double-bladed knife, like the twin motor-saw, insures accuracy of fit. The paraffin dressing provides immobilization and access to light. From Albee, "Principles of the Treatment of Non-Union of Fractures," *Surg, Gynec. & Obst*, Sept., 1930, 51, 3 299 By courtesy of *Surgery, Gynecology and Obstetrics.*

consists of the laying down of new cells, partly by the host and partly by the scion, which eventually fuse host and scion.

It is thus evident that the cells of the scion preserve their vegetative and proliferative power. The reëstablishment of the circulation is simpler in the plant, but it is obvious that the sap must permeate the cells of the scion or the latter will eventually die. In bone, reëstablishment of the blood circulation becomes a problem, the solution of which governs the whole question of surgical technic.

Of all the layers in a tree-bark—alburnum, wood, and heart—the alburnum is the important one in grafting, since it is the proliferation of its cells in scion and host that brings about the union. In bone, and especially in long bones, the structure is more complex and all the layers, periosteum, cortex, endosteum, and marrow take part, to a greater or lesser extent, in union.

Immobilization is effected in plant grafting in two ways: in addition to the fixation provided by the accurate fit of the scion, the site of grafting is either bound with many layers of fabric or is covered with wax, or better, paraffin. These sealing substances serve as a sterile dressing as well, since they keep out fungi. If paraffin is used, immobilization is just as secure, and light (especially the ultraviolet) is allowed to penetrate to the wounded tissues and especially to the bud which needs the ultraviolet for the metabolic activity of its chlorophyl.

Plant grafting and bone grafting thus have the same objective and are carried out according to the same fundamental principles. The appli-

cation of these in bone must be more meticulous since there are added difficulties in a relatively highly specialized tissue nourished by a system of closed vessels

In the plant the graft and host tissue must be maintained in close apposition, other than this the only force to be counteracted is that of the wind and this only when the scion is a large shoot In bones there is the pull of muscles both tonic and voluntary and the exaggeration of the former by reflex from pain Fixation and immobilization therefore present difficulties which must be met in a special way

Bancroft s statement in regard to union of fresh fracture is even more applicable to the union of the bone graft The most important factor for the union of a fracture is to have the fractured ends in close apposition and to have an adequate blood supply to allow the ingrowth of granulation tissue with the resultant ossification to form callus Adequate blood supply and coaptation are even more necessary in the case of the graft because the stimulus which a recent fracture gives to osteogenesis is lacking in the old fragments In the fresh fracture there is usually an adequate supply of blood in marked contrast to the ischemic state of a pseudarthrosis Union of the graft therefore proceeds under difficulties that must be counterbalanced by the most careful methods in its application

Vascularization and Life of the Graft —Just as the union of fracture fragments is fundamentally similar to that of severed soft tissues so the union of bone grafts with the host is similar to that of fascial or tendon grafts (Fig 2) It has not been shown that in either of the latter the graft is replaced by overgrowth of local tissue Garlock investigated the stages of union and the fate of a tendon graft The experiments reported in this paper show definitely that the graft lives as such His description of the nutrition of a tendon graft may with suitable changes be applied to that of a bone graft It is probable that the graft derives considerable nutrition from the tissue juices It is probable that the main source of nutrition is from the outgrowth of young capillaries and lymph vessels from the tendon ends and from the subendothelial tissues of the sheath

When I was in England in 1929 Sir Arthur Keith the eminent clinical pathologist wrote me that he had some specimens at the Museum of the Royal College of Surgeons which he would like to show me Upon complying with his request I was much impressed with the pronounced vascularization of specimens of grafts inserted for various purposes which he had obtained from postmortems and injected and prepared with the particular purpose in mind of demonstrating this phenomenon

The early and complete vascularization of a graft has been very striking and interesting to me since my early animal experimental work in 1910, and I believe it to be one of the underlying causes of the extremely beneficial action of the bone graft when inlaid in the spine or through other tuberculous joints such as the knee, the tarsus, etc. (See

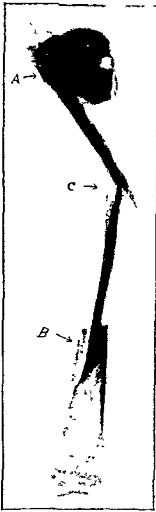


Fig. 2.—Roentgenogram of two grafts, each three inches long, inserted by the author for a tibial defect from the removal of 2/3 of its shaft for sarcoma. Because it was impossible to remove all of the tumor, immediate amputation was indicated, but permission to do so was refused. In the dilemma, two short grafts were obtained from the involved shaft and they were tied together at *C* by encircling kangaroo tendon. At the end of 4½ weeks, the family were finally persuaded to allow amputation. In this short space of time, the callus formation at *C* between the two grafts was so strong that under lateral pressure, fracture of the graft occurred below *C* rather than through the callus. Further remarkable osteogenesis of the bone graft is borne out by the fact that in this short space of time, not only were the grafts firmly united to each other, but also to the tibial fragments at *A* and *B*. The query thus arises: Where did the new bone cells originate if not from the ends of the graft themselves? From Albee, *Orthopedic and Reconstruction Surgery*, W. B. Saunders Co.

Figs. 27 and 86). This factor emphasizes the importance of accuracy of fit of the graft and host tissues, and also the importance of using a massive graft of ample length, as such a degree of beneficial vascularization could not be accomplished by bone chips. Under such conditions the haversian canals of the graft rapidly become canalized and increase in size in precisely the same way as we get a collateral circulation established when important blood vessels have been cut or occluded.

The various layers of a bone graft freshly removed present raw surfaces wherever they have been cut The vessels are severed but still contain blood which tends to clot at the point of section The various tissues of the graft are capable of survival for a considerable time, but it is of the first importance to restore its blood supply and nutrition The graft must be placed in the most favorable environment for this end If it is so placed that the elements of the graft (periosteum, cortex, endosteum and marrow) make direct and intimate contact with similar elements in the host, the soft tissues of the bone first unite across the slight gap, vascular continuity of host and graft is reestablished through periosteum, endosteum, and marrow, and a granulation tissue bridge is laid down between the bony surfaces (Fig 3) Osteoblasts appear in the granulation tissue and determine the deposition of lime salts If the process follows Bancroft's picture of healing bone, the continuity of the haversian systems will be indirect until the normal architecture has been established between the graft and the host Under ideal conditions, the greatest possible number of capillaries of host and graft are brought into the closest mutual approximation The entire graft will then remain intact If such conditions are not provided smaller or larger areas of the graft will fail to be nourished and will ultimately be replaced The process by which the bony structure of the graft is later rearranged to conform to the structure of the host is in no sense absorption The process can be called assimilation, if the term is used in the sense that the graft assimilates itself into the host The graft is not the subject of processes imposed upon it by the host it is itself the active agent in its own rearrangement under the influence of the stresses which it encounters in its new environment, it has the power of adaptation The question of whether the bone graft lives when properly placed in a favorable environment has been answered positively in the affirmative during the past thirty years of the author s personal experience, both in the animal research laboratory and in the clinic at the operating table and the follow up of over 6,000 cases (Figs 4, 5, 6) The x ray is by all means the most trustworthy method of study, not even excepting the microscope With its aid the welfare and development of a graft over many years may be followed Both in the case of animal work as well as clinical, if for any reason part of a graft became dead, as from infection, the x ray never failed to disclose it There could never be any doubt about the continued life of a scion such as in the apple tree A scion from a sweet apple tree when grafted into a tree bearing sour apples will always bring forth sweet apples of the exact variety of the tree of the scion's origin This

same phenomenon occurs throughout the vegetable kingdom so long as scions are grafted into one of its own family.

If all the elements of the graft cannot be brought into contact with similar elements of the host, the marrow at least should be. Johnson's conclusion that the circulation was reestablished, 75 per cent by the marrow and 25 per cent by the periosteum, indicates the share which each tissue has in osteogenesis.

That the blood supply is the key to the situation is shown by certain clinical observations. When a large anemic scar surrounds the region

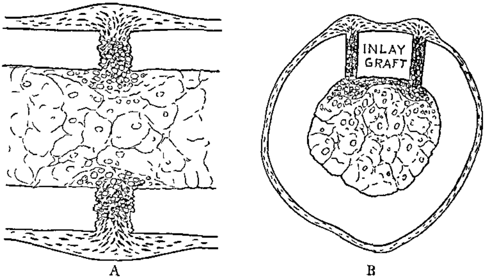


FIG 3—*A* represents a so-called greenstick fracture with perfect apposition of the corresponding bone layers, (periosteum, compact bone, endosteum and marrow substance) of one fragment to the other. Bone growth is thus under the most advantageous condition and is the product of the coordination of all these layers. Therefore the conditions in this respect, in a greenstick fracture are ideal for a rapid union. The histological conditions and coaptation of like bone layer to like bone layer are the same in the instance of the inlay graft, *B*. From Albee, *Orthopedic and Reconstruction Surgery*, W B Saunders Co.

of nonunion, it is admittedly good practice to replace the scar with a pedicled skin graft laid right on the ununited fragments. Union occasionally follows such preliminary treatment. In any event, the chances of union are much enhanced by the methods which improve the circulation to the tissues adjoining the nonunion and through them to the periosteum of the fragments and of the graft, if one is inserted. Correspondingly, the chances are diminished by interference with the circulation to the graft. The original fracture may have been accompanied by laceration of tissues, such as tendons and nerves, which still demands repair. The operations should be undertaken in order of their urgency,

and the success of the bone graft should not be jeopardized by another operation performed at the same sitting Extensive dissection not only necessitates prolonged exposure of the wound to the air but interferes with the circulation to the soft parts Many of the smaller blood ves-

Fig 4—Longitudinal section through spinous process with cross section of graft (*ABC*) which had been inserted six months from a low power photomicrograph of a non decalcified ground specimen *Numerous blood vessels can be seen under high magnification extending* from spinous process into graft *D* is new bone *E* is base of spinous process From Albee *Bone Graft Surgery* W B Saunders Co

sels are severed or occluded as the result of the trauma Tissues in this state constitute a very unfavorable environment for the bone graft

When the fragments of a nonunion are osteoporotic, the chances of union, instead of being diminished, are actually increased Osteoporosis is associated with increased vascularity, and this must account for the rapidity of union of a bone graft in such cases

Relation of Coaptation to Union.—The approximation of graft to host is analogous to closure of a wound in soft tissue. If the opposing surfaces are poorly approximated, much granulation tissue is required to fill the gap, and healing is slow. If the surfaces are brought into close

Fig 5—Decalcified section through long axis of spinous process with cross-section of the grown-in graft, six months after a portion of same animal's ulna had been grafted into spinous processes A careful microscopic study of these sections and all others had failed to disclose dead bone cells. The corners of the graft are indicated by *a*, *b*, and *c* (*d* is a microtome artefact) From Albee, *Bone Graft Surgery*, W. B. Saunders Co.

contact, the layer of granulation tissue is of small thickness and healing by first intention results. This speedy granulation tissue union not only reëstablishes the circulation in the graft at the earliest moment, but results in the deposition of the thinnest possible layer of callus between the bones. This necessitates the least possible rearrangement of the callus trabeculae. It is thus evident that not only the viability of the

graft but the promptness and durability of union and the rapidity of assimilation of the graft to the host tissues depend on close approximation of graft to both host bones. In nonunion, the surgeon will find that nature has little callus for him and he must make the most of the meager supply; he must draw on mechanical principles to compensate for the meagerness of the physiological reaction.

When a graft containing all four elements is placed in intimate contact with the same elements in the host, it acts as a vascular and osteogenetic unit; vascular union proceeds along the lines of natural repair and a bridge is placed between the two fragments which calls for the minimal amount of trabecular and vascular readjustment to take on the function of the host bone it replaces. If the graft is inserted or attached in any other way, vascular communications are limited (and the viability of the graft thus jeopardized) and the graft may have to be largely or entirely reconstructed by nature before it assumes the structure suitable to the stresses exerted on it. It is under such circumstances that absorption may occur.

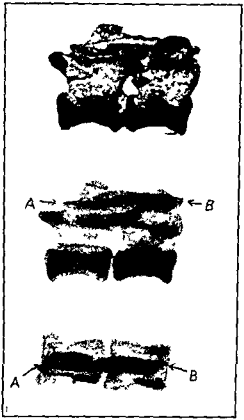


Fig. 6.—Photograph and roentgenograms of an ulna autogenous graft, *AB*, six weeks after being inserted into the spinous processes of a dog's vertebrae. The roentgenograms show firm union and no osteoporosis or degeneration of the graft. From Albee, *Bone Graft Surgery*, W. B. Saunders Co.

Relation of Immobilization to Union.—When soft tissues are uniting, their flexibility minimizes the danger of disruption of the granulations. When such rigid tissue as bone is uniting, the least displacement may tear the granulations and blood vessels or fracture the soft callus. Hence, the necessity for the most accurate and stable immobilization. From the mechanical standpoint, the advantage of "internal" immobilization needs no corroboration. Here again, the inlay graft is superior: it exemplifies the mechanical principle of the slot and key.

When the healing fragments and the graft are thus held in rigid immobility, the granulations and callus are protected not only between graft

and host but between the two host fragments. The stress of maintaining immobility falls on the graft and, under this influence, the graft grows in size and strength (in accordance with Wolff's law) and adapts its structure to the stress. A graft, the size of a pencil, when inserted to take the place of a portion of the femur, will grow to the dimensions of the host bone and assume an identical structure, by its power of adaptation.

Necessity for Power Driven Tools.—The entire process of union and the survival of the graft depend on the establishment of vascular connections between the graft and the host fragments; the rapidity of establishment and the degree and permanence of vascularization vary directly with closeness of coaptation and rigidity of immobilization; these depend on accuracy of fit. The necessity for the greatest precision in the mechanical procedures needs no further argument; ideal conditions can be produced in no other way than by the use of automatic power driven tools which can be adjusted to cut with mathematical exactness both the graft bed and the graft which is to fill it with "glass stopper" precision.

Fortunately, all bones are filled with cancellous tissue or marrow and are thus well suited to the inlay technic. The universally adjustable twin saw which the author designed twenty-seven years ago serves ideally, as similar tools have served similar purposes in the industrial world.

Relationship of Mechanical, Physiological, and Biological Principles. —The most unfortunate and the most general misconception of the treatment of nonunion is that it is a mechanical problem. The idea is inherited from the principles of the treatment of fresh fractures. The traditional methods are based entirely on mechanics: how to overcome distorting forces and how to maintain alignment by the application of counter forces or stress. If, after reasonable reduction and immobilization of the fragments, union fails, the problem passes from the realm of mechanics into those of physiology and biology. It is not to be expected that repetition of mechanical methods will be successful, since the stimulus to granulation and ossification has abated. Even in the open treatment of nonunion this faulty conception is evident. Methods are commonly practiced which have no other basis; and there are surgeons who apparently believe that two pieces of bone must unite if held together and that the method of approximation and means of maintaining it have no bearing on the success of the operation, other than through mechanical fixation.

In one case that came under my observation, the surgeon had begun by plating the fragments (Fig. 7). When failure by this method was evident in due course, he used wire; after another disappointment, he resorted to nails. The third failure did not by any means shake his con-

fidence in purely mechanical means, with a persistence worthy of a better cause, he put all three back—plates, wire and nails Four times did he try to find a mechanical antidote for the particular case He did not fail for lack of skill applied to a piece of furniture, his repair would have outlasted the original Approximation and fixation are essential,

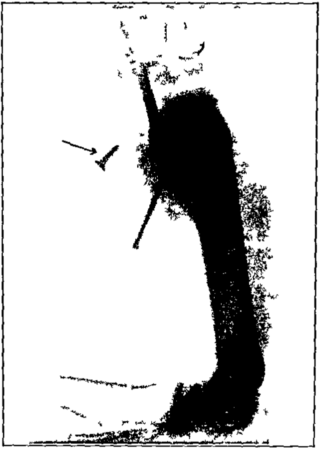
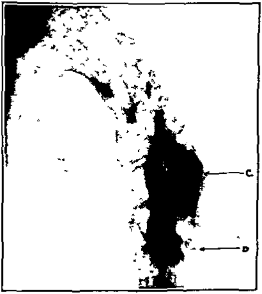


Fig 7.—Metallic relics of four different operations which had the mechanical aim of promoting union and the physiological result of preventing it From Albee *Orthopedic and Reconstruction Surgery* W B Saunders Co

but these are only means to an end—the union of the fragments by the production of new tissue from one to the other

I have tried to trace the reparative processes following the introduction of the bone graft, from the formation of granulation tissue to the incorporation of the graft as an integral part of the host tissue We know that all tissues react to changes in environment A fractured bone manifests the greatest reparative power during the period immediately following the injury Since injury thus stimulates repair, it is clear that

A



B

Fig 8.—A, resection of femur for osteogenetic sarcoma and immediate replacement by massive graft, *AB*

B, same as *A*, after fracture of graft at an unknown time while patient was in cast following the operation The remarkable outpouring of callus from the lower end of the upper graft fragment *C*, extends to point *D*. Callus is also present on the inner side of the lower fragment of the graft. Firm union occurred in ten weeks.

the freshly removed graft has potentialities for repair that will become fully manifest as soon as it can establish its vascular connections (Fig. 8). This reaction to environment takes the form of increased metabolism. As the graft takes on its function of immobilization, its metabolism

A B C D

Fig 9—Incorrect and correct methods of inserting a graft into a smaller long bone The almost inevitable disaster awaiting the attempt to put an intramedullary graft into the radius is illustrated in *A*, which shows fracture of one host fragment, and in *B*, which shows the later absorption of the radial fragment and of the graft The successful application of the double-wedge-end graft is illustrated in *C D* shows the thorough amalgamation of the graft two months later From Albee, "*Principles of the Treatment of Non Union of Fractures,*" *Surg, Gynec. & Obst*, Sept, 1930, 51, 3 302 By courtesy of *Surgery, Gynecology and Obstetrics*

is further stimulated by the demands of its environment. The adaptive response is increase in size and strength, and this is just what occurs Later, the graft must adapt its structure to its new position and the stresses it encounters. Thus function determines structure, and modification of function brings about modification of structure.

Other Grafting Methods.—*The intramedullary graft* has not justified the early hopes of those who advocated it (Fig. 9). Rather faint-hearted

recommendations of it are still occasionally seen. At its best, the method is applicable only to the largest bones: the femur, the tibia, and possibly the humerus. In all cases where eburnation and sclerosis extend back for a long distance, the limb must be materially shortened or the graft must be left lying loosely in a hole through dense bloodless bone. Granting that the marrow is the most important source of blood supply for the uniting structures, the process of reaming it out is manifestly

A B C

Fig 10—*A*, extensive bone loss of lower end of radius with angulation of distal fragment from gunshot wound

B, implantation of strong inlay graft, *IG*, with supplemental onlay, *OG*. The inlay became *firmly amalgamated with the radial fragments and produced a most satisfactory* result, whereas the onlay, because of its poor environment and blood supply, became devitalized and had to be removed

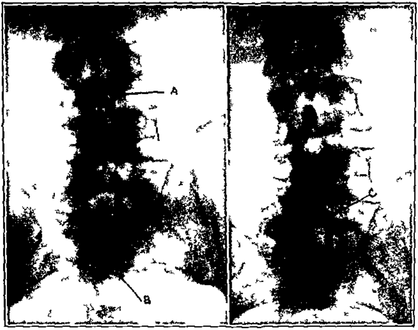
C, end result same as *B*, showing firm union of inlay and onlay graft removed.

prejudicial to union and is contraindicated. The technic makes accurate coaptation of graft and host impossible, so that vascularization of the graft is uncertain and defective; nor is there any strict immobilization, since all the graft does, or is expected to do, is to prevent gross lateral displacement.

Failure of union after the application of an intramedullary graft is an unusually vexing problem because of the destruction of the marrow and the consequent aggravation of the ischaemia of the fragment ends generally.

The *osteoperiosteal graft* was first advocated by Ollier The osteoperiosteal graft provides no mechanical continuity since it consists of soft tissue to which plaques of bone cling It, therefore, cannot exert an immobilizing effect and, on that account, cannot be influenced by Wolff s law

Instead of the periosteal graft, I use the sliver graft which has mechanical continuity, contains all four bone layers, and because of its con-



A B

Fig 11—*A* showing boiled ox bone implant following attempted fusion of lumbosacral spine It was already broken into three fragments with displacement of the lower fragment *B*

B x ray three months after *A* showing the upper two fragments of boiled ox bone absorbed with the lower fragment at *C* remaining The author removed it and found that it was incorporated in granulation and scar tissue with no evidence of vascularization or union to the spinous processes to which it had been contacted This has been true of all such cases where beef bone was employed

tinuity, responds to Wolff's law It can be taken very quickly with the motor saw from the side of the gutter where the large fixation graft has been obtained Because of its thinness, it adapts itself to irregular bony contours by pressure of overlying parts The sliver graft should be used as a supplement to other grafts

These objections apply to a degree to the *onlay graft* as well, except that anatomical continuity is preserved When the onlay graft is used in a case with much scar and tenseness of the overlying soft structures,

there is always the difficulty of covering the graft, especially when it is applied to the bones of the forearm or the tibia. It is often a case of choosing between covering it incompletely and using undue tension in approximating the skin and soft tissues over it. Any procedure which increases the original diameter of the bone is, in this respect, hazardous in many cases (Fig. 10).

The use of *boiled animal bone* is especially to be condemned: its osteolytic effect has been demonstrated both experimentally and clinically. Boiled ox bone has been repeatedly referred to in the literature as a bone graft, but it cannot be regarded as such inasmuch as it has been devitalized by boiling. Furthermore, assuming it were used in an active state and the bone cells were still alive, it would still be most unsatisfactory as a source of bone graft material because of its heterogenous nature. Such tissue would provoke a local foreign protein reaction in the host and jeopardize the possibility of a successful result. The author has upon many occasions removed living sheep bone implanted months and even years previously (Fig. 11). In no instance was the graft ever found to be united in the slightest degree with the human bone. This heterogenous bone material was always found to be demarcated from the surrounding bone by a cavity filled with serous fluid—a typical foreign body reaction.

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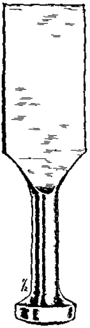
CHAPTER II

ARMAMENTARIUM OF THE ORTHOPEDIC SURGEON

In no field of medical science are the tools with which the surgeon works of greater importance than in bone and joint surgery. Speed and accuracy of cutting are essential in the shaping of a hard, brittle substance such as bone. Also, from a mechanical standpoint, many of our modern operations, which deal more and more effectively with deformity, would be impossible of execution were it not for the electrically driven machine tools which were adapted by the author from industry thirty years ago, and have been constantly added to as necessity arose. The reduction in operating time, in shock to the patient, the precision of work and the mechanical intricacies of reconstruction which it makes possible, place the bone mill first in the essential operating room equipment of the modern surgeon who undertakes to do work of this nature. And, with equal importance, comes skill in its use.

A bone and joint trial kit made up for the Medical Corps of the Army in the Great War was submitted for my approval, and I found that the instrument makers had apparently introduced a jeweler's mallet, and although the cutting edges of the chisels and osteotomes were satisfactory, the handles were most unsatisfactory in that they were short and very small in diameter. It might seem to the casual surgeon that the handle of a chisel or osteotome was not so important; but those of us who are using these tools daily realize what an important feature of these instruments the handle is. It is by the surgeon's grasp of the handle that he is able to direct the cutting edge of the tool accurately, and in working in deep wounds, executing precision in bone or joint work as well as in close proximity to important structures such as blood vessels and nerves, it is most essential that he have complete control of the direction of the cutting edge at all times. Again, a handle either short

in length or small in diameter cramps the surgeon's hand after it has been used for any length of time This of course, is realized by the carpenter and the machinist and this part of their hand tools is given the consideration it deserves



F g 12 —Albee osteo ome for spl t t ng sp nous pro ces es By courtesy of K y Scheerer Company

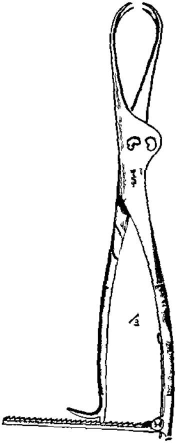


Fig 13—Albee s frac ture tenaculum espec ally des gned for reduct on of fracture of the patella grasp ng head of femur in reconstruct on opera t on and approximat ng other fracture fragments in general See F g 152 By courtesy of Kny Scheerer Company

Osteotomes should be of various sizes from ¼ inch up to the broad osteotome used for splitting the spinous processes (1½ inches wide) (Fig 12)

The Mallet—The artisan whether he be cutting stone, sculpturing

marble, or shaping wood or iron, uses a hammer, mallet or maul, the head of which is of sufficient weight, so that by the use of its inertia, the cutting tool may be driven forward with the greatest precision and control. This is illustrated by the finest of sculpture work. It is necessary that the face of the mallet shall be uniform, and that the end of the chisel or osteotome which receives the blow shall be of similar uniform surface, and of a hard substance such as metal. I do not at all approve of the wooden handled osteotomes, such as those of Lexer. I believe they make for inaccuracy of control of the cutting edge of the tool.

Albee Bone Tenaculum.—For over fifteen years, or ever since I began doing my reconstruction or partial arthroplasty operation for old ununited fractures of the neck of the femur, I have constantly realized the difficulty of extracting the head of the femur from the acetabulum by means of any available instrument. I have, therefore, devised the instrument shown (Fig. 13). This illustrates the sharp prongs of the clamp designed to pierce the head of the femur. The head is quickly and readily removed by twisting it as it is withdrawn. This clamp has other uses, such as extraction of the upper fragment of a fracture at the anatomical or high surgical neck of the humerus which has been displaced into the axilla; or holding the fragments of the patella together while an inlay graft is put in place, etc.

Figure 152 shows the instrument holding the fragments of an ununited fracture of the patella together while an inlay graft is being inserted.

The Improved Albee Bone Mill.—The Albee bone mill consists of a complete set of instruments—as complete as the carpentry mill which permits the surgeon, under absolutely sterile conditions, to perform the necessary tasks of bone carpentry and cabinet making, with the precision of a machine shop in commercial carpentry. The outfit consists of:

1. Rotary saws of different diameters.
2. Universally adjustable twin saws, or the cutting caliper.
3. Various types of reciprocal (oscillating) finger-type saws for deep work, circular osteotomy, scroll work or cutting of segments of any size of circle.
4. End mill cutters for enlarging gutters, mortices, etc., and for starting drill holes on oblique, hard or slippery bone surfaces.
5. Drills of various sizes and types, up to one-half inch for the neck of the femur.
6. Lathe for manufacture of living bone graft pegs and screws of different sizes.
7. Corresponding size drills for pegs or screws.

8. Different size taps, to cut threads on the inside of the drill holes.

9. Die cutters, to make threads upon bone graft pegs of different sizes.

10. Motor-driven oscillating chisels and files.

11. Laminatome used with great advantage in cutting laminae rapidly in laminectomy and in osteoplastic flap work on the skull, particularly for wide exposure with preservation of the skull flap intact (See Fig. 63).

With the aid of this apparatus, it is possible to make bone graft inlays for the treatment of ununited fractures, bone tuberculosis, etc., as

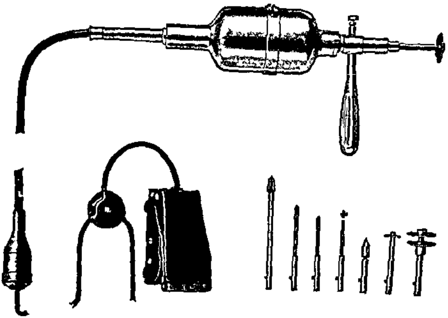


Fig 14.—Albee bone mill with foot switch, saws and drills. See text, page 20. By courtesy of Kny Scheerer Company

well as autogenous bone pegs and screws for various types of reconstruction surgery, chronic fractures, bone plastic surgery, etc In fact, all types of bone surgery involving the cutting or shaping of bone are rendered possible. It is the only motor-driven outfit which possesses the versatility of circular saws, drills, peg and screw-making devices, reciprocating cutting tools, and laminatome for laminectomy and osteoplastic skull work.

The Bone Peg and Screw Threader.—This has been newly designed in order to turn out bone pegs and bone graft screws which will automatically and accurately fit into drill holes (threaded or not) made by various sized drills

A universal motor (Fig 14) is attached to a lathe, equipped with cut-

ting tools which are able to form pegs or screws of any desirable size (Fig. 15). Peg shapers and dies, which may be used interchangeably, form the bone grafts themselves (Fig. 16). A concave peg-shaper is

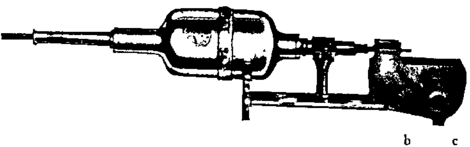


Fig. 15.—Universal motor attached to lathe, which is able to form, with its cutting tools, pegs and screws of various sizes. *b*, peg-shaper; *c*, screw-shaper. By courtesy of Kny-Scheerer Company.

first used to shape the end of the graft in conical form (like the action of a rotary pencil sharpener) in order that the graft may be optimally engaged in the peg-shaper and then in the die.

Various-sized drills are included, some for pegs and some for screws

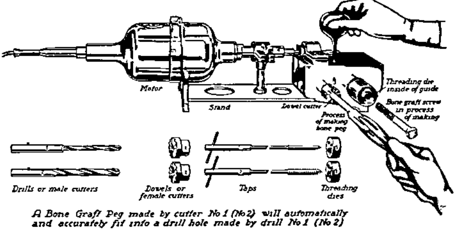


Fig 16—Motor attached to miniature lathe and screw-cutting device. See text, page 21. By courtesy of Kny-Scheerer Company.

(Fig. 17). These are differentiated because the relation in size of the peg-shaper to its corresponding drill is different from that of the die to its corresponding drill. The drills are therefore marked "for peg" or "for screw."

After the use of the drills to make appropriate sized holes, taps

(Fig. 17) are used to form threads in the drill holes. These taps, of different sizes to conform to the drills, must be driven slowly for best success, and are accordingly best guided by hand.

The motor-driven lathe consists of a housing with gears, so designed that the peg-shaper revolves at a desirable speed and the die at a much slower speed, an essential for good results. The surgeon gently pushes the bone graft through the die, forming screw threads upon it to any desired length, while the completed portion protrudes through the far

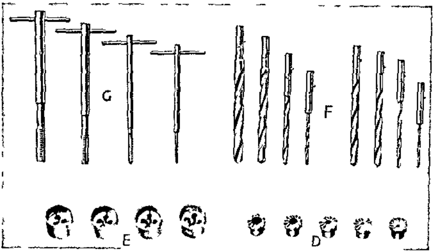


Fig 17.—*D are peg-shapers, and E, dies which may be interchanged to make pegs and screws of any desired size when inserted in the lathe shown in Fig 15 At the extreme right of D, is the conical peg shaper used in first shaping the graft, in order to point it properly F, drills of various sizes used in preparing the hole to receive the peg or screw The drills are differentiated according to whether they are to be used for pegs or screws G, taps of different sizes for making threads in drill holes These are most advantageously used by hand rather than driven by motor By courtesy of Kny Scheerer Company*

side of the lathe. If a head is desired on the graft screw, it is not pushed completely through the die. To remove the screw from the mechanism, the surgeon merely pulls gently upon the instrument which holds the graft; this reverses the rotation of the die and automatically the screw is ejected. The mechanism performs in precisely the same way as the reverse gear of an automobile transmission (Fig. 16).

The apparatus is capable of being sterilized by boiling. It requires little care, although the surgeon should familiarize himself with its parts and capabilities A screw-plug in the lathe housing enables the special lubricant to be changed

Oscillating Saw Attachment.—For special purposes, we have de-

signed an oscillating saw attachment, which has proved of distinct value, particularly in circular osteotomies or other circular bone incisions, and in cutting deeply situated bones (Figs. 18, 63).

If there is an adequate marrow cavity on the inside of the bone cortex to cut, one might safely use the oscillating saw. However, most frequently *this is not the case; even large marrow cavities may be completely filled* with extensive plugs of eburnated bone, as in ununited fractures. The oscillating type of tool is an adjunct for very special purposes, and we have designed a complete set of these cutting tools, driven directly from the armature shaft of the motor itself which we find definitely preferable to the flexible shaft as it makes for stability and cutting power of the tools. The flexible shaft has been abandoned as a method of power transmission on dental engines, because it causes vibration and chattering of the cutting tool. This is of particular disadvantage in starting a drill or saw and is extremely undesirable in any precision work, such as straight or mosaic inlays. On the *other hand, it is desirable to have the cutting tool* attached to the motor armature shaft, as it makes for *accuracy and expedites the cutting of cortical bone, which* is very hard. A "flexible shaft" which will drive without buckling when a large tool, such as a twin saw, is driven rapidly through adult bone cortex, must be so large in diameter that it is no longer flexible. Any really flexible shaft will buckle. One apparatus has attempted to prevent "dancing of the drill" driven by a flexible shaft by a telescoping gage which is clumsy in operation.

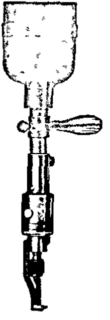


Fig 18.—Albee's oscillating saw attachment See Fig 63 for use in laminectomy. By courtesy of Kny-Scheerer Company.

We have found that the most advantageous power-driven cutting tool for hard surfaces is the rotary one; that is true in bone surgery as well as in manufacturing *industries. As a matter of fact, the rotary saw is of particular merit in* surgery, as the bone to be cut is surrounded with important soft tissues, and, as a rule, can be approached from one side only. The rotary saw allows the surgeon to penetrate from one side, as far as he elects, without permitting the cutting tool to penetrate the full thickness of the bone.

The foot switch is an important part of the outfit. It enables the surgeon not only to turn the current completely on and off, but by means of a rheostat-control he is able accurately to control the speed of the cutting tool. This is a valuable feature in that it allows the surgeon to start the operation of his drill at a low speed, thus permitting him to

start a drill hole on the smooth surface of hard cortical bone without difficulty The low speed tends to obviate wandering of the drill over the surface of the bone before it becomes fixed at the desired point of entry

A slowly revolving saw is much more likely to catch and pull side ways in the soft tissues or bone, therefore, it should usually be run at full speed

It is a well known fact that when cutting hard materials in machine shops, oil or some water is kept in constant contact with the edge of the cutting tool For the same reason, in using the motor saw, *the saline drip not only entirely prevents the generation of heat but it enables the saw to cut more smoothly and safely*

Cutting Instruments—*The single (circular) saw*—about 1¼ inches *in diameter—is used more than any other of the cutting tools* These *saws are made of the best steel and are very thin and are held on the* shafts by means of nuts which allow the saw blades to be changed whenever they become dulled Saw blades should be changed as soon as they become dulled precisely as a razor blade

In the *single saw*, the type of tooth should always be that of a cross-cutting saw (*i e*, a tooth shaped like an isosceles triangle), and should have very little "set"

The *twin saw* (Fig 14) is so constructed that it can be adjusted to any desired width even to the fraction of a millimeter It consists of two single saws, which can be used singly or together Each is mounted *on a separate shaft, one of which is hollow so that the other can be inserted into it and so bring them to any distance apart that may be* desired, according to the size of the bone being operated upon and the width of the graft or gutter to be formed

The *small saw is* used for cutting the ends of the inlay graft or the strip of bone which is being removed to produce a gutter On account of its small size (¾ of an inch) the saw does not encroach upon the gutter walls while it is cutting across the inlay and therefore, does not weaken the remaining portion of the tibia

The *guard* with *spray* is rarely used because it obscures the surgeon s view of the saw By extensive experience it has been found that in the *majority of cases a few drops of saline solution constantly dripped upon the saw from a rubber ear syringe held by an assistant, serves every* purpose

In determining the size of the inlay or gutter, the saw teeth are placed on the exposed bone in the manner of a compass or calipers, with the

saws adjusted a proper distance apart. This is accomplished by grasping the knurled ring attached to the proximal saw and turning it anticlock or tocque-wise of the motor at the same time the saw is slipped to or from the distal saw. The slightest stress tocque-wise upon the saw firmly locks it in place on the shaft. The saw blades can thus be set any distance apart desired.

The *dowel instrument* or *lathe* is fastened into the universal motor by the automatic catch, precisely as are the other cutting tools. The speed or rotation of the dowel cutter is reduced about ten times by bronze gears (Fig. 16).

The size of the bone graft dowel or peg is regulated by the size of the cutter which is adjusted in the lathe. The largest cutter is for turning out a bone spike for a fracture of the neck of the femur. The smallest one is for making pegs with which to hold inlay grafts in place. The medium-sized cutter is for making graft pegs such as are used for pinning the scaphoid to the head of the astragalus in an arthrodesis for advanced clubfoot, or for pegging on a fractured tuberosity, or as a substitute for metal nails and screws in any situation where they might be indicated.

A *cutter, after the pattern of a rotary pencil sharpener* (Fig. 15), has been added to the motor outfit for the purpose of fashioning a conical tip on a peg-graft of any size, so that it will engage either in the dowel-shaper or threading die with greater ease and to enable it to be driven through a drill hole in cancellous bone if desirable. These cutters can be rapidly interchanged, and slipped in and out in a moment's time. After the tip of the graft has thus been "sharpened," this conical cutter is removed and a dowel-shaper of the size desired is inserted and used in the manner about to be described.

The dowel-shaper (Fig. 16) is used by first attaching it to the motor and then placing the apparatus parallel with and on the edge of the instrument table. While the assistant steadies the motor and lathe by gently pressing the same on the table, the operator, holding with a strong clamp the piece of bone to be shaped, pushes it into the dowel-cutter. When withdrawn from the dowel-shaper, it is a perfectly round dowel and is ready to be driven into the drill hole formed by a drill of corresponding size. The strip of bone from which the peg has been fashioned, is obtained by means of the single or the twin saw, usually from the tibia. If of small size, from the anteromesial surface; if of large size, as for the hip, from the crest. If a bone graft screw is desired, the peg after being withdrawn from the dowel-shaper is fed into the threading die (Fig. 16) while the motor is going at full speed. The threading die is

revolving slowly because of reducing gears When the threading process is complete a gentle pull upon the newly made bone screw causes the die cutter to reverse its rotation and the bone graft screw is slowly ejected

The *notched drill* (Fig 129) is a simple device but is very effective in saving time and labor After the desired hole has been made the motor is stopped and a ligature slipped into the notch Upon withdrawing the drill the ligature comes with it and thus avoids the subsequent use of a needle or other instrument for threading the ligature through the drill hole

Sterilization (Hartley Kenyon Method) —The parts to be sterilized are first removed from the motor by releasing the plunger on the end of the electric cable and pulling it out This part of the electric cable from the motor to the black rubber union on the connecting cord is boiled The handle is removed after first releasing the thumb screw which locks it and the shell to the motor beneath The shells are then removed and together with the cutting tools sterilized by boiling

Use of Bone Mill —After sterilization the operator picks up the long part of the shell with his gloved hand and holds it with its large open end up The nurse holding the large end of the motor in the palm of her hand inserts the other end into the recipient shell and turns the motor to the right as far as it will go or until the spring plunger on the out side of the shell snaps into position The operator can then manage the motor alone by grasping the sterile half shell which is firmly secured to the motor The second half of the shell is placed over the other end of the motor and is locked in place to the first shell by first lifting out ward the spring plunger so that the second half will go under the edge of the first half shell until the plunger goes back into the hole in the motor housing (Fig 19) The guide handle is placed over the neck of the motor and securely fastened by the set screw The connecting plunger on the side of the electric cable is then inserted through the sleeve on the shell into the motor This portion of the electric cable with its metal tube and block connectors is especially constructed to withstand steriliza tion by boiling The connector on the other end of boiled short cable is next inserted into the black connecting block in the central portion of the cable leading from the socket of electric supply to the foot switch which the nurse has previously connected and arranged with the foot switch in a convenient position for the surgeon s controlling foot while he is operat ing The motor is then ready for use

The *saws* or the *cutting tools* are inserted by turning them over a little to the left or until the spring engages the slot on the side of the shaft of

the instrument. The cutting tool is unlocked by a slight turn of the saw at the same time that the instrument is withdrawn. The action of the motor is controlled by the foot switch which makes and breaks the elec-

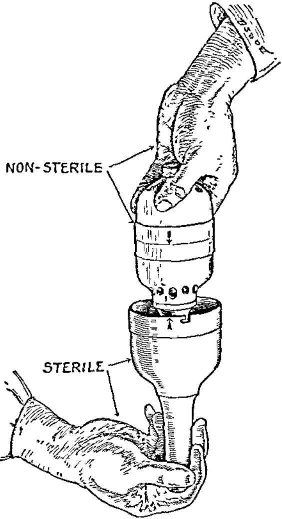


Fig 19.—In assembling the motor, the surgeon holds the recipient shell (its orifice uppermost, like a goblet), both the shell and the surgeon's hand being sterile. An assistant (whose hands are non-sterile) inserts the shaft of the motor (which has not been sterilized) into the recipient shell and turns it to the right until it can be turned no further and the arrow on the shell comes in line with the arrow on the motor. From Albee, *Orthopedic and Reconstruction Surgery*, W. B. Saunders Co.

tric circuit as well as controls its speed. The surgeon thus has the uninterrupted use of both hands and the most precise speed control of the cutting instruments. In certain plastic work, especially fracture work, it may be necessary at one operation to employ several different cutting tools, such as two sizes of single saws, twin saws, oscillating saws, dif-

ferent sized drills, and surgical lathe as well as to interchange these several times The *automatic catch permits of almost as speedy interchange* of motor tools as of hand instruments and is a most important feature of the outfit

Technic of Using Motor —*When the motor tool is cutting, the handle* is held in the operator s right hand the base of the motor is grasped in the left hand and the right foot manipulates the foot switch which is *placed on the floor beside the operating table at a place convenient for* the operator's foot If found necessary, the position of the motor and hands may be reversed The various technical applications of the outfit *will be illustrated in detail in the discussion of surgical technic in succeeding* chapters

The surgeon should, from the very beginning of his work with the *motor driven instruments, acquire the invariable habit of removing the* cutting tool immediately upon the completion of a given maneuver, before laying the motor down upon the table This is done very quickly

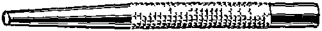


Fig 20—Albee bone drift prototype of the carpenter s nail set This is an instrument which I use very frequently in seating grafts whether they be of the inlay type peg type etc It is used similarly to the carpenter s nail set

and simply, and consumes very little more time than is required to pick up and lay down any other instrument *The motor with the cutting instrument removed is devoid of danger, while the same instrument carrying a cutting tool is a constant menace to the surgeon and his assistants* The foot accidentally touching the switch may start the motor and the fingers of the operator or assistants may pay the penalty, or if the motor is lying on the table the cutting tool may catch in the dry goods roll and the motor may, as a result, fall on the floor

My "hip shapers" or reamers, modified from Murphy's, consist of *two hemispherical, cup shaped instruments mounted in heavy solid metal* handles, one being used for smoothing off the roughened femoral head, *the other for reaming out the acetabular cavity The concave surface of* one (for the femoral head) and the convex surface of the other (for the acetabulum) are furnished with radiating ridges or cutters which are put into operation by a rotary to and fro movement These instruments are of value in preparing the hip for arthroplasty (See also Figs 20, 21)

Fracture Orthopedic Table —The necessity for some external means of traction and leverage in the treatment of fractures and deformities of acquired and congenital origin is exemplified by the time honored use

of weights, screw devices, sand bags, pulleys, etc. More exact mechanical methods in the form of traction tables are of comparatively recent origin and appear to have been devised primarily as aids to the reduction of congenital dislocation of the hip.

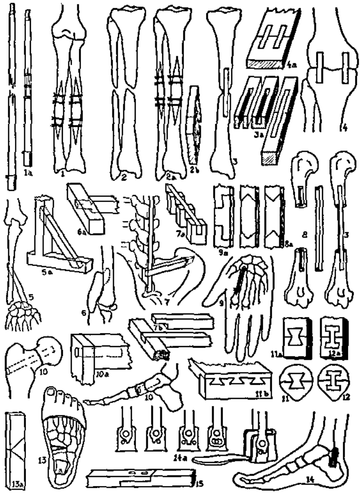


Fig. 21.—The fine joinery element in bone surgery—a group of self-evident analogies. Numbers 11 and 12 are keyed in tension members in broken knee caps which will not join. No 14 is a stop, made of the patient's own bone, to prevent the foot from dropping. No 14a is the analogy—a brace made of metal. The bone surgeon must be a skilled mechanic before he can become proficient in his field. From Albee, 'Bone Surgery with Machine Tools," *Scientific American*, April, 1936, 154, 4.

The fracture-orthopedic operating table finds its chief field of usefulness in accomplishing at the operation that which the Balkan frame or other allied apparatus does at the bedside. With it the surgeon in the operating room can obtain the same degree of immobilization and fixation in "position of neutral muscle pull," and various mechanical postures

which he can secure at the bedside by traction with the above mentioned apparatus

In order to obtain the same results, it is necessary to employ a frac ture orthopedic table possessing a wide range of adaptability, *i e*, all the various positions of neutral muscle pull so essential to the successful treatment of fractures and readily attainable at the bedside by the above methods can be secured in the operating room only by a table which will not alone permit traction in any desired direction upon either the upper or the lower extremities but will also hold the affected part so fixed during the application of the plaster of paris dressing that neither the traction nor the position of neutral muscle pull on the one hand nor the *alignment of fragments on the other will be deranged*

Such requirements have not been fully and successfully met by any traction table yet on the market The chief deficiencies of such tables have been (1) Length and weight of table (2) The difficulty in mov ing the table about, due to the absence of swivel trucks (3) Projecting *traction arms and other attachments, preventing use as a general operat* ing table (4) Limitations as to adjustments which would permit impor tant positions of neutral muscle pull and other indicated postures of the extremities (5) The axis of the traction arm has always been placed at the center of the table, which is far internal to the axis of abduction *adduction of the hip joint This is a most serious objection the axis of* the traction should be made adjustable to variations of width of differ ent pelves in every instance the axis of the arm has been in the center of the table far internal to the actual axis of the hip joint, the result being that in attempting to abduct or adduct the limb, the amount of *traction is never the same for the axis of the limb is eccentric under* these conditions the movements of the traction arm into further abduc tion markedly diminish traction (6) The lack of gradations in elevating or depressing the lower half of the table is a distinct deficiency, it has been necessary in all tables either to completely raise or lower this sec *tion (7) Raising the depressed end of a fragment by former tables* could be secured only by overhead methods which were an encumbrance to the operator

Each of the above objections has been overcome in the Albee Comper fracture orthopedic operating table (Fig 22)

Details—The *trucks* of the table rest on swivel rollers, permitting it to be moved about easily while a locking apparatus over the two at the lower end, operated by foot, permits it to be easily fixed in the desired place The ability to move the table about easily is of the greatest con *venience, in that any time during the operation the table can be so moved*

that better light is secured in the depth of the wound, or one's clinical observers can be afforded a better view of the operative procedure. The tables previously manufactured do not possess this locking apparatus and the wheels at the foot are not swiveled.

By the turning of a handle, the table may be placed in the Trendelenburg position for spinal anesthesia, or for the treatment of shock occurring during the course of an operation (Fig 23). Incorporated in the general design of the table, is provision for the use of a canvas sling for

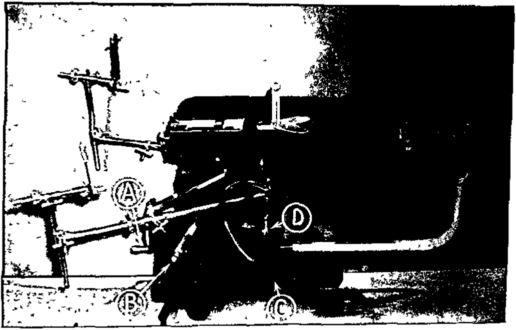


Fig. 22—Table in lateral tilt. Foot-section shown removed to permit assistant to stand between patient's legs in close relation to operating surgeon For application of hip-spica cast, buttocks-section of table lowers, and head-section draws back to permit start of cast at axilla. By courtesy of Comper Manufacturing Company.

hyper-extension in the prone position as described by Davis for reduction of vertebral compression fractures (Fig. 26-C). The overhead post to which the feet are attached, may be raised or lowered by the turning of a handle, which also insures the canvas sling clinging to the lower abdomen and pelvis during the maneuver. This simplifies the application of the plaster cast. The overhead post is also designed for Sayre's suspension.

A removable leaf at the foot, and a hinged leaf at the head allow the table to be lengthened as much as necessary, while a removable shelf steadied by a rest, can be used for instruments or to support the arm or leg of the patient.

Hip rests are of two sizes The head of the table is movable up and down from the hip rest, so as to allow the application of various widths of spicas

The table together with the traction arms may be raised or lowered to the height most convenient to the surgeon, independent of this height

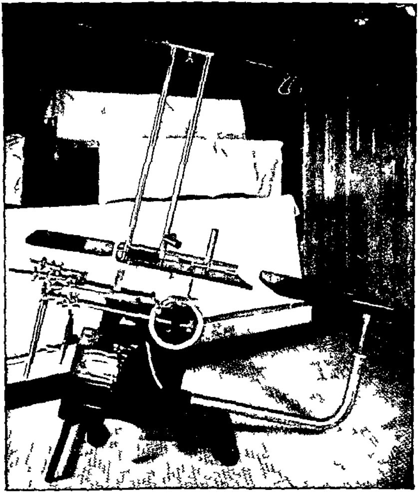


Fig 23—Table in Trendelenburg angle for spinal anesthesia or treatment of shock during the operation By courtesy of Comper Manufacturing Company

range of the entire table the foot end is capable of being elevated or depressed to any desired height by means of a wheel with handle This *ability to raise or lower the foot end* of the table by graduated adjustment is an important innovation in that it allows sand bags or pillows to be placed beneath the sagging ends of fracture fragments, which may be elevated to the proper alignment by a few turns of the

wheel, the handle of which is accessible to the surgeon, by whom it may be grasped under a sterile towel, so that at any time during the operation the surgeon has the *mechanism of the table under his* complete control. If the surgeon is dealing with a hip case, he is enabled by depressing this portion of the table and inserting a sand bag *under one buttock*, to

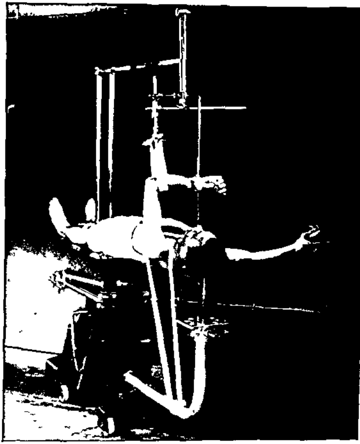


Fig 24.—Anterior elevated position Steel strip, or canvas-sling, substituted for table-top. Traction rods swing into position and leg traction screw is transferred to overhead frame. Anchorage to base structure is for firm counter-traction. By courtesy of Comper Manufacturing Company.

have complete control of the upward rotation of the patient's hip or pelvis in any degree desired, both before and during the operation.

The *long traction arms* are telescoped, and therefore allow sufficient shortening so that they can be swung under and out of the way when the table is being used for general purposes and traction is not required. The space occupied when not in use is thus considerably diminished. Lengthening of the traction arm is accomplished by two adjustments.

Coarse adjustment is attained by graduated telescoping of the arm, and a more powerful, fine adjustment accomplished by means of a screw This screw differs from those of previously constructed tables in two respects First, it feeds distally as well as proximally when the wheel is turned Failure of this back feed has proved a great annoyance in other traction tables which the writer has used Second, the screw threads are covered by a metal cuff which prevents jamming of sheets or towels into the threads while traction is being made

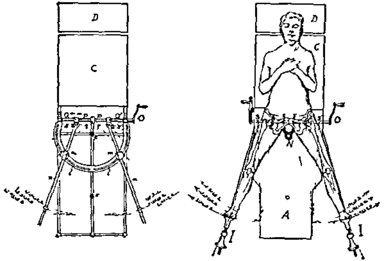


Fig 25—Screw adjustment of proximal ends of traction arms a mechanical device for shifting centers of rotation of traction arms to points corresponding with or greater or less than *interval between hip joints of individual* Crank (*o*) turns bar (*p*) halves of which have worm threads cut in opposite directions Turning crank moves riders (*q*) and (*q'*) simultaneously keeping them always equidistant from center of table Pivots of arms (*n*) and (*n*) *are thus made to travel along lines from 1 to 3 and 1 to 3* respectively enabling abduction or adduction of these arms to describe arc of a new circle with each new position Traction arms can be fixed upon quadrant *1 1* in any given position by set screws (*m*), (*m*) From Albee *Injuries and Diseases of the Hip* Hoeber

The foot is held in position by a muslin bandage placed over it and *including in its fold the movable flat bar, placed against the plantar surface of the foot* and the curved plate beneath the heel These flat bars (foot plates) are very strong, being made of steel of sufficient thickness to resist yielding in certain other traction tables the foot plate bends These plates fit into the distal extremities of the traction rods, at which point the *small sliding curved plate* prevents compression of the heel and obviates dropping down of the foot due to the obliquity of its dorsal aspect where the bandages encircle it during the application of a large *amount of traction* This sliding plate prevents *the foot from skidding* downward away from the foot piece, an accident which commonly occurs

in some traction tables. After plaster of paris dressings have been applied, and the restraining muslin bandages cut, both of these sliding plates are removed, thus freeing the patient's limb from the traction arm without disturbing the plaster. The table has been so designed throughout as to make way for the use of the fluoroscope and x-ray exposures in setting fractures, etc., during operations.

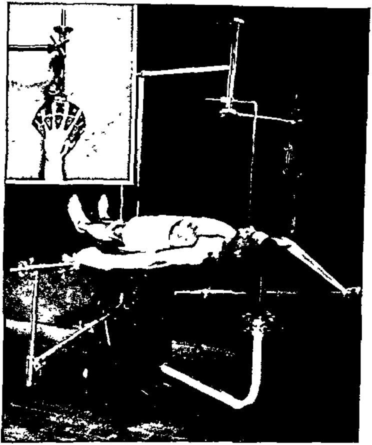


Fig 26A—Airplane position. Apparatus is universally adaptable to conform to various postures Note Weinberger hand-traction fixture. Courtesy of Comper Manufacturing Company

Screw-adjustment of Pelvic Ends of Traction Arms.—The proximal ends of the traction arms are universally adjustable by means of a heavy screw placed cross-ways to the table. This screw bar is placed (to correspond with the *horizontal plane of the hip joint*) *slightly above the* perineal post (the horizontal plane of the symphysis pubis). See Fig. 25. The distance apart of the perineal post and the screw bar of the traction arms represent an average of comparative measurements of various pelves.

The direction of the threads of this screw bar is reversed on the opposite side of the center, so that when the attached crank is turned the ends of the traction bar uniformly converge upon or diverge from the center of the table This enables the surgeon to make his adjustments in accordance with the width of pelvis of each individual case so that traction remains constant throughout abduction or adduction which is usually desired However by placing the axes of the traction arms farther apart the amount of traction may be increased as abduction is increased the opposite result is secured when the axes are placed nearer

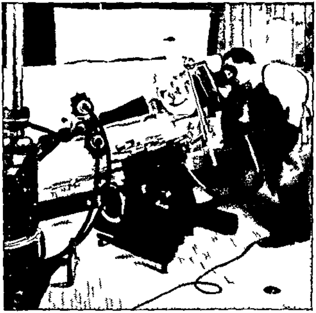


Fig 26B.—Lateral view through neck of femur The quickly detachable table sections and compact pedestal base speed up the positioning of x ray tube and the super or posturing through lateral tilt should be noted Courtesy of Comper Manufacturing Company

the center In the management of dislocations and fractures near the hip the former may be an important and valuable adjustment

Countertraction is supplied by means of a perineal *traction post*

Traction on the Upper Extremity —In the year 1908 the writer first described the anterior elevated position as the position of neutral muscle pull for controlling epiphyseal and surgical neck fractures of the upper end of the humerus This position and traction are maintained both during the operation and the application of the plaster of paris spica (Fig 24)

Rotation of Table with Patient During Operation —While this posture and traction are maintained the whole table and patient can be

rotated so that an operative field on the outside of the shoulder will be upward, thus avoiding the surgeon almost standing on his head in order to secure good vision of his operation. This is the only table in which this is possible, and is extremely useful for hip joint surgery.

To release the patient from the table after the application of the shoulder spica, it is necessary only to cut the bandages external to the

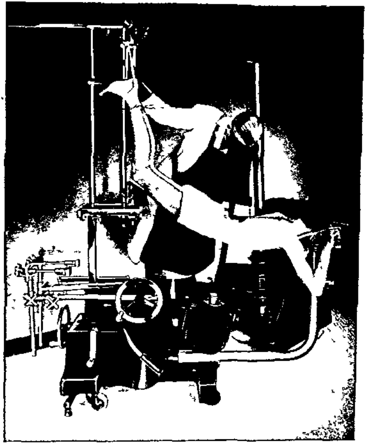


Fig. 26C.—Fluoroscopic check with slender patient in hyper-extension (Davis position). Note unique construction in Albee-Comper fracture table giving empty space under entire trunk for positioning of x-ray tube. Courtesy of Comper Manufacturing Company.

plaster, disengage the wrist rest, pull out the cross-bar and axillary holds, elevate the patient's shoulders and remove the backrest board. If it is desirable to fix the arm in the abducted lateral position, traction and fixation may be secured by abducting the leg traction arms to a right angle with the long axis of the table and applying traction by straps above the wrists in precisely the same manner as in traction upon the lower extremity.

In the case of fracture of the forearm, or in the region of the elbow, or humerus, or both in the same case, adhesive stickers may be applied to the point of fracture, left in place and covered by the plaster dressing, or a carefully applied wristlet may be employed

Uses—1 It may be used for the reduction by the closed or open method of fracture of the extremities, particularly about the hip or upper third of the femur The maintenance of traction and the limb posture (as neutral muscle pull) during the application of the fixation dressing, *viz*, the anterior elevated position of the upper arm in the case of fracture of the upper end of the humerus (position of neutral muscle pull) or the abduction flexion position (neutral muscle pull) of the thigh in fractures just below the lesser trochanter

The table is of great utility in the mechanical fixation position of abduction (Whitman) in fractures of the femoral neck

During traction, lateral displacement of fragments can be corrected by direct pressure The rough edges and serrations in oblique or transverse fresh fractures can be utilized under the influence of traction to interlock the fragments and maintain reduction

The importance of full surgical anesthesia is inestimable in the case of all fractures, in order to obtain complete muscular relaxation

2 In compound comminuted gunshot fractures, where the necessity of limb posture is doubly indicated on account of the inability to make the most of coaptation splints because of the loss of large amounts of soft tissue

3 The reduction of dislocations (traumatic or congenital) and the maintenance of limb posture during the application of fixation dressings

4 The application of plaster of paris fixation dressings in the treatment of joint diseases, etc

5 Joint resection, osteotomy osteoplasty, arthrodesis, etc

6 Application of plaster of paris jackets, particularly in the hyperextended position

In addition to a traction operating table and the bone mill, a complete armamentarium for doing up to date and efficient bone surgery should contain the following

1 Suitable retractors, sharp pointed and rake, and of varying sizes and depth of tooth

2 Bone clamps and bone jacks

3 Bone elevators (*e g*, Lane's)

4 Materials for external and internal fixation of fragments, kangaroo tendon of heavy sizes

5 Provided the surgeon has not fully developed his technic, so as

to avoid the use of metal, various metal plates and tools for their application.

I believe that the wood screw, adapted only for soft materials, should never be used in bone, and only a self-tapping screw should be used.

Furthermore, I am convinced from a very careful laboratory investigation and wide clinical experience, that silver wire should be *entirely omitted* from the surgeon's armamentarium in fracture work. It is a treacherous agent because it is so likely to break at the twist, where it is fixed. It is surprising how little force large strands of silver wire will withstand when placed in an accurate machine for testing tensile strength. In many instances, the wire will begin to yield at the twist or knot before the dial of the testing machine has begun to register.

The special sizes of kangaroo tendon as a fixative agent for bone have the following advantages:

(*a*) They are much stronger even than catgut, silk or silver wire.

(*b*) They are absorbable, but not too rapidly so. They remain in bone for upward of forty days, and then begin to disappear.

(*c*) They can be tied in a firm, tough, non-slipping knot.

(*d*) They do not stretch, as silk-worm gut does.

(*e*) Kangaroo tendon is comparatively easy to sterilize and is not at all irritating to the tissues.

6. *Osteotomes* of various widths. *I never, under any circumstances, use a blunt-edge chisel.* There is so little flexibility and fiber in bone that it crushes or breaks very readily under the chisel, and for that reason a thin-edged osteotome is preferable.

7. Rongeur.

8. Lion-jaw forceps.

9. Gouges with long handles and of various widths.

10. Heavy mallet; it should be large and of solid metal, although one of lignum vitae is very good.

11. Suitable materials for external fixation dressings. The importance of this should be emphasized. Suitable materials consist of plaster of paris roller bandages and "strengtheners" (the latter are of the greatest service), as well as cotton, sheet wadding, stockinette or flannel.

12. The Balkan bed-frame.

13. Thomas' knee-brace, and other necessary apparatus.

Plaster of Paris Technic.—*The Plaster of Paris Bandage.*—The reason for the limited use of plaster of paris bandages in private practice as compared with their extensive use in dispensary and hospital practice is undoubtedly to be found in the fact that those in the market do not fulfil the surgeon's requirements.

Instead of crinolin, many of these plaster of paris bandages are made of some unsized material, or, if crinolin is used, it is of too fine a mesh and wound too tightly Furthermore, these bandages usually contain too much plaster, and therefore, when an attempt is made to saturate them the water is unable to gain access to the interior of the bandage and fully to saturate the plaster, in consequence of which dry lumps are left which interfere with the uniform setting of the plaster

Again, the plaster of paris is frequently of inferior quality and the bandage is not hermetically sealed Because of the hygroscopic nature of the plaster, it takes up moisture, "cakes," and the process of satisfactory setting is effectually prevented

Plaster of paris hardens by a process of crystallization If moisture-laden air is allowed to gain access to the bandage, those particles of plaster which are more hygroscopic than others will crystallize prematurely, *producing gritty particles in the plaster, which can be easily recognized by rolling a specimen between the fingers When such a bandage is in the process of application, it hardens slowly and irregularly, and solidifies unequally* This is a great disadvantage because it is imperative to maintain correction of a deformity from the outset, without delay, and to be able to mould the plaster properly so as to increase coaptation pressure to prevent relapse of the deformity

Materials —PLASTER OF PARIS —The plaster of paris should be that used by dentists, of superior quality, and rapidly setting (That manufactured by the S S White Dental Company has been found by long experience to be the best) It is packed in air-tight tin pails to prevent hydration from the air It may be said in passing that to further prevent hydration, the pails should be stored in the intervals between use in dry localities, and when in use the hand introduced into the pail should be perfectly dry

It will occasionally be found that because of some accident during the process of manufacture or from a break in the hermetic seal, a particular specimen *of this plaster will not harden properly Such a specimen* should either be returned at once to the manufacturers, or put through a slow baking process, for the purpose of dehydration

When this hermetically sealed dental plaster is used, the addition of salt to the water of immersion is not only superfluous but is an undesirable procedure, because it causes the plaster to become brittle

CRINOLIN —Although a number of different fabrics have been used as a material for impregnation with plaster of paris (gauze, dextrin gauze, flannel, etc), it has been found that crinolin (gauze sized with some stiffening substance) is by far the most satisfactory for this pur-

pose. An unsized bandage is worthless in this connection, while crinolin of too fine a mesh is unsatisfactory. A bandage containing too much sizing is open to the objection that the excess of sizing material prevents the plaster from setting.

The crinolin which many of our largest clinics have found by experience to be the most satisfactory, is the hospital crinolin labelled *H*, *manufactured* by the H. B. Claflin Corporation. The mesh should number 28 or 32 threads to the square inch. It comes in 12-yard bolts.

Method of Preparing and Storing Plaster of Paris Bandages.—After the bolt of crinolin has been divided into two equal portions, each 6 yards in length, the selvage is removed by tearing, and roller bandages of 3 and 5 inch widths are produced by tearing the half bolt lengths longitudinally. After winding these strips into loose rolls, the ravellings on the edges are removed by rubbing the point of a pair of scissors over the ends and pulling away the ravellings thus dislodged. (Crinolin should never be *cut* with knife or scissors unless cut obliquely, after having been rolled, because of the difficulty of always following between the same longitudinal threads and thus avoiding short ravellings which cannot be removed on account of the uneven cut edge.

Impregnation of the Crinolin Bandage with Plaster.—This is best done by placing a pile of plaster upon a smooth broad board (such as a bread board) and drawing the crinolin bandage through it. The bandage is held to the left of the pile, slowly unrolled, and dragged through the edge of the pile of plaster. While the bandage is being drawn through, the plaster is rubbed by hand thoroughly into the meshes, *the meshes should be rubbed just full and no more.* No additional plaster should be sprinkled on the bandage, and care should be taken that the latter is not wound too tightly.

Storing.—The completed plaster of paris bandage is wrapped in a single layer of paraffin paper which is impervious to moisture, and secured with an elastic band, or, for lack of this material, in two or three layers of newspaper or wrapping paper, and packed in tin pails with accurately fitting covers. The pails should be kept in the driest place available. Plaster of paris, whether loose or in bandages, should never be stored in a basement. If for any reason the air-tight seal of the pail becomes broken and the plaster fails to harden well and quickly, it may be possible to restore it by placing the tin container with the cover off in a *very slow* oven for a period of several hours, after which the cover is replaced and the container set away in a dry place.

Plaster of Paris "Strengtheners."—In addition to the ordinary roller form of plaster of paris bandage, the so-called "strengtheners" are of

much value when used at points of great mechanical stress, *e g*, at the groin in the case of the spica These are made precisely like the ordinary plaster of paris bandage, with the exception that instead of being rolled, they are reduplicated into 2-foot lengths of about 9 thicknesses

These 9 folds are then loosely rolled up, an elastic band put about each, and they are either placed in a separate container, or, if put in the same tin with the roller bandages, they are wrapped in a specially colored paper for the purpose of identification

Instead of plaster of paris "strengtheners,' *metal* is sometimes used for this purpose, tin, zinc, or sheet iron, although I prefer the plaster "strengtheners' except in the rare instances in which unusual strength is required or when a cast has been weakened by fenestration

Requirements of a Plaster of Paris Bandage —The crinolin should be of such quality that in applying the bandage, it can be made to conform smoothly to the irregularities of the part to which it is being applied

The bandage should be so wound and so impregnated with plaster that when properly immersed in water, it will become immediately saturated and during the process of application, will not "telescope," *i e*, if too tightly wound and containing too much plaster, it will have dry spots from uneven penetration of the water, if too loosely wound it will "telescope'—the center pushes out at one end As has been said the strongest and most efficient bandage is one that contains just enough plaster to fill the meshes of the crinolin and no more

The plaster should harden with sufficient rapidity so that when the surgeon has completed the final layers, the bandage will be of such consistency as to give good splint support, and yet be malleable enough to withstand moulding and stay "put'

Padding —Several materials have been used as padding, cotton sheet wadding, stockinette, flannel all of which are acceptable I prefer to use sheet wadding purchased in large rolls and torn into strips varying from 4 to 12 inches in width and rolled into bandages One advantage of cotton wadding is that it yields to Stille s cutter in removing the cast in a way that the other materials do not Emphasis should be put on the importance of the *even* application of this sheet wadding due regard being paid to the protection of all superficially placed bony prominences, at the same time preserving its even distribution through the rest of the limb Another advantage is that on account of its yielding properties, it never furnishes a constricting edge to cause distal swelling of the limb I prefer to hold the wound dressing (postoperatively or otherwise) by means of the sheet wadding bandage, rather than by applying a gauze bandage directly over the sheet wadding bandage, as practiced by some

surgeons, because the general swelling of the limb from exudate after any operation may cause the edge of the gauze bandage to become taut, and to act as a local constricting band, *causing further swelling of the limb distal to that point.*

Saturation of the Plaster of Paris Bandage.—Tepid water is ordinarily used, always in a container (preferably a pail) of sufficient depth so that with the bandages standing on end, they will be entirely submerged. The higher the temperature of the water (within certain limits), the quicker the plaster hardens. The wrapper, if it is permeable to water, may be left on or removed, as preferred; I prefer its removal. The bandage is placed on end in the water and allowed to remain stand*ing until air-bubbles have ceased to rise, when it is ready for use; time is* no guide to the completion of saturation, the absence of air-bubbles being the criterion.

Attempts to hold or to squeeze the bandage while it is submerged, with the idea of making it absorb water more rapidly, cause agglutination of the ends of the bandage and prevent the water from penetrating to its center.

After removing the bandage from the water, it should be held by each end, with the object of preventing, so far as possible, the escape of *the fluid plaster. It should then be very gently wrung out by a half turn* of the bandage, so that when handed to the surgeon, it is in the shape of a flattened roll with about 6 inches unrolled. The saturated bandage should never be squeezed in the center or vigorously wrung, because thereby too much plaster is lost and frequently the bandage is telescoped.

"Strengtheners" are saturated in the same way as the roller bandages above described.

Application of the Plaster of Paris Bandage.—It is difficult to give clear and comprehensive directions for applying an ideal plaster of paris bandage. *Dexterity can be acquired only by actual experience.*

The best method is to allow about 6 to 8 inches of the bandage to be unrolled in advance of its actual application. *Great care should be taken* to have the bandage smooth, without wrinkles, and with its first layers so placed that slight, even compression is exerted throughout the extent of the splint. The plaster should be *constantly* rubbed in during the application.

The limb is first entirely and evenly bandaged with two or three thicknesses; this insures a more uniform bandage and promotes more rapid hardening, since it gives a larger area for drying. It is difficult to state exactly how many layers should be applied in the average case; the *quality of the plaster*, the rapidity of drying, the character of the lesion,

and the mechanical stress that will come upon the splint largely determine this Roughly estimated, the average plaster of paris dressing, from groin to toes when completed, consists of 6 to 10 thicknesses, but the splint should always be made as light as safety will permit

The "strengtheners" above described may always be used to strengthen that part of the splint on which increased stress or moulding is to come, thus avoiding a generalized increase of bulk and weight of the cast, incidentally, the use of "strengtheners" lessens the time of the technic

In the case of a prolonged application of an extensive splint, the water should be changed at frequent intervals, since it becomes saturated with plaster and hence thickened, and fails to penetrate the bandages readily The surgeon should be careful to mould the plaster about the bony prominences and be on the alert to increase his coaptation effect at the proper time, before the plaster becomes too hard

Rubbing in dry plaster or plaster cream on the exterior of the dressing, hastens hardening and gives a smoother surface When it is necessary to maintain the plaster in position for a long time, to keep it clean, particularly about the fenestra, and free from contamination and saturation by discharges, varnishing the cast is an excellent practice

It is advisable to turn down a cuff of the sheet wadding over the edges of the cast at its extremities when it has been partially applied, so that the remaining portion of the cast can be placed over it, this not only serves to hold the cotton at the edge, to secure its padding effect, but also to prevent the patient from dislodging or pulling out the cotton at this point If it is necessary to trim the cast, the production of a cuff should be delayed until the trimming has been completed, when one or two layers of the plaster of paris bandage may be added for the purpose of holding the cotton in place

In cases in which large fenestra are to be cut, it may be necessary to strengthen the dressing at those points by means of metal bridges incorporated in the plaster and carried over the fenestra

Where traction is required, moleskin stickers, or whatever traction straps are used, are placed upon the limb at the desired points, emerging at the lower angles through openings made during the course of application (In the case of the lower extremity, at a point 2 or 3 inches above the malleoli, a spreader being applied below the foot and weights attached in the usual manner, or moleskin can be incorporated into the plaster for positive traction)

Plaster dressings well applied and of good material will last many weeks or months, in fact, I have removed plaster of paris jackets that have been in place for five years

As a rule, the potency of a plaster of paris dressing is due largely to its leverage action, and it should, therefore, be sufficiently long to allow this factor full value. In the case of a lesion of the knee joint, the cast should always extend from the groin to the ankle or toes; in the femur, a spica over the pelvis.

Accessories to Plaster of Paris Bandages.—JURY-MASTS.—In cases of cervical Pott's disease or other lesions of the cervical spine where fixation support is required, a jury-mast or chin-cup may be incorporated in the last layers of the plaster jacket. No other special means of retaining the apparatus in the jacket is necessary.

Removal of a Plaster of Paris Splint.—In my experience, this is best done by a Stille cutter. If this is not accessible, a saw or a heavy jackknife serves the purpose.

To soften the plaster along the line of incision, vinegar can be used after the surface to be cut has been well scarified with a knife. Hot water also serves the same purpose. Having cut the gutter, the dressing is spread with a special clamp.

In the case of the lower limb, it is best to cut along the outer margin of the foot behind the external malleolus and up the external surface of the leg, rather than along the instep and inner surface of the thigh, where the plaster hugs the limb more closely. In removing a cast which has been applied for postoperative fixation, the field of operation should be carefully avoided. The same rules apply to the removal of the plaster of paris spica, in that one should avoid the thicker portion of the bandage at the groin where the portions from thigh to pelvis cross each other. The best method for removing the spica is to cut up the inner surface of the leg as far as the perineum, thence over the abdomen.

If it is desired to make a removable plaster corset, the dressing is cut from the symphysis up the midline of the abdomen and thorax to the sternal notch, then sprung off the trunk and the hooks and eyes and the covering of the corset applied, so that it can be laced together like an ordinary corset.

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CHAPTER III

SPINE FUSION

The spine fusion operation has come to be regarded as a procedure of major importance in the armamentarium of the modern bone surgeon. The story of its evolution constitutes an interesting chapter in the history of present-day orthopedics. Although a number of operations had been previously performed on the spine for purely cosmetic purposes, it was Hadra of Galveston, Texas, who, in 1891, first attempted to stay the progress of a spinal curvature by twisting silver wire about the spinous processes of the sixth and seventh cervical vertebra in a case of fracture-dislocation.

Lange in 1910, presented before the American Orthopedic Association, a method which he had tried wherein celluloid plates were placed on either side of the spinous processes, secured by metal or silk sutures. The suggestion was offered that if some means could be provided for immobilizing the posterior arm of the vertebral lever, a consequent arrest of the increasing deformity and disability could be rendered more certain.

In a folder of the American Orthopedic Association, published May 15, 1911, the author described a method of ankylosing together the spinous processes of tuberculous-infected vertebrae by autogenous osteoplasty which seemed to offer advantages over the methods previously employed, whether conservative or operative.

The technic employed upon four cases consisted of splitting the spinous processes longitudinally in halves, fracturing these halves at their bases, freeing them of ligamentous and muscular attachments, throwing one-half down to contact with the fractured base at the fractured half of the spinous process below, and turning up the other half to contact with the

base of the fractured half of the spinous process above, and so on until a sufficient number of spinous processes had been so dealt with as to include the entire area of the diseased vertebrae, and one or two healthy vertebrae above and below

In these cases, which were all children, this ligamentous covering, together with what periosteum was found, was separated from these spines and sutured over and about the arranged split fragments of the spinous processes In this way an attempt was made to ankylose together the posterior segments of these vertebrae and thus actually to prevent all intervertebral motion from respiration or muscular action, and finally, to stop the crushing together of the diseased bodies of these vertebrae (It should be noted that practically the whole spinous process is covered with ligamentous and muscular attachments, consequently there is very little actual periosteum obtainable)

Since this method consumed much operative time, and as there was an element of uncertainty in bringing about this desired ankylosis, the author was influenced to adopt the much simpler bone graft method now employed Animal experimentation using the same technic devised for internal immobilization of the human spine, provided experimental corroboration of the operation (Fig 27)

Although originally described for the treatment of Pott's disease, the operation has been equally effective in the hands of the author and other bone surgeons in the treatment of a wide range of pathological conditions, namely

(*a*) Tuberculosis of the spine (Pott s disease)
(*b*) Scoliosis
(*c*) Vertebral fractures
(*d*) Congenital deformities
  1 Spina bifida
  2 Hemivertebra
(*e*) Spondylolisthesis
(*f*) Chronic osteomyelitis
  1 Pyogenic
  2 Typhoid
(*g*) Other conditions
  1 Osteoarthritis
  2 Charcot spine
  3 Vertebral epiphysitis and osteochondritis
  4 Tumors of the vertebra
(*h*) Affections of the sacro iliac joint

TUBERCULOSIS OF THE SPINE

I regard Pott's disease as a distinctly surgical affection, and operative treatment as *sine qua non* to be given precedence over other therapeutic measures. Nonoperative mechanical treatment is reserved for patients

Fig. 27.—View of a dog's vertebra into the spinous process of which a portion of his ulna had been ingrafted by the author six months before. *A*, *B* and *C* indicate the outlines of the graft, which has become firmly grown into the split spinous process. *E* is articular facet. From Albee, *Orthopedic and Reconstruction Surgery*, W. B. Saunders Co.

who refuse surgical intervention, or who are not good surgical risks, and for postoperative use.

The two methods most commonly used now are the extra-articular arthrodesis with inlay tibial graft which I first described in *1911*, and the intra-articular fusion of Hibbs.

The marked curative effect of bony ankylosis upon any tubercular joint is axiomatic Without ankylosis, an advanced tuberculous process in any joint can rarely be said to be cured In planning treatment of tuberculous spines, it is therefore of extreme significance that, anatomically, we are dealing with a joint under constant uncontrollable influences which move it, such as respiration and involuntary muscle spasm This fact contributes greatly to the spread of the tuberculous process, disintegration of involved bone and operates against cure It not only makes it more difficult for Nature to set up a protective ankylotic process in a bone with a low degree of osteogenesis but also presents increasing difficulties to the surgeon who attempts to bring immobilization about by nonoperative measures

Disadvantages of Conservative Treatment —These nonoperative measures include the application of casts and braces and the use of the frame and the block The plaster cast must be judged according to the general principles of splinting Since both thorax and abdomen normally change their dimensions constantly, the cast cannot be fitted closely enough to maintain immobility, and this cardinal principle of splinting must be sacrificed It cannot be expected that any form of external splinting will immobilize a series of short bones of irregular contour to which are attached muscles acting in coordination with the muscles of respiration and the voluntary muscles which move the head and limbs An added disadvantage to these imperfect attempts at immobilization is that the cast which is applied to accomplish cure of the spine seriously restricts the movements of the thorax and abdomen and interferes with the oxidation and nutrition on which so much depends in the treatment of any form of tuberculosis This in itself is paradoxical

If the cast is applied to a child during the period of growth, the tendency to produce muscle and bone atrophy by prolonged incumbency and inactivity is most unfortunate biologically, anatomically and physiologically, and in my opinion far outweighs any objection to submitting a child to an operation of so slight magnitude (ten to fifteen minutes' operating time) with such outstanding curative influence, as opposed to prolonged conservative treatment which so often is followed in a year or two by relapse If the patient is referred for operation at this stage, the disease has frequently progressed to such a degree that deformity cannot be entirely corrected or prevented The late end results of cases in which the bone graft operation for Pott's disease was performed in early childhood are so favorable, and I have seen so many tragic cases resulting from unsuccessful, prolonged, conservative treatment who seek operation too late, that I stand emphatically for early operation Recent

literature shows that more and more surgeons are inclining toward this view.

If there is a complicating apical lung focus, the cast tends to aggravate it by constricting the lower lobes and leaving the upper relatively free, thus throwing increased mobility and work on the diseased portion of the lung. The extent to which distortion of the abdominal contents may be carried is illustrated by the extreme degree in which the abdomen sometimes rolls out from beneath the lower end of cast.

The Bradford frame and the block are not open to all of these objections, but they have their own disadvantages, the most important of which is the protracted inactivity of the patient, and the fact that one never can be certain there will not be a relapse as long as there is no bony ankylosis.

Spinal Fusion by Tibial Graft.—One, therefore, turns to internal immobilization by means of an autogenous bone graft as the procedure of choice. My first attempts in 1909 were directed toward fusion of the spinous processes without using bone graft material from elsewhere. I was not satisfied with the ultimate results, and the more I examined the principles on which the operation was based, the more faulty did this procedure seem. The spinous processes supplied an insufficient amount of bone to anchor or fuse the vertebrae securely, and of still greater fundamental importance was the consideration of its extremely low osteogenic value.

As evidence of this is the progressive lysis of vertebral bodies in the traumatic condition known as Kümmell's disease, and the progressive dissolution of tuberculous vertebral bodies resisted by so inadequate a reparative reaction of an osteogenetic nature. *Secondly, in the case of a* broken lateral process, although the fragments may lie in perfect apposition, they do not unite in more than 5 per cent of cases. Further, Spies, who has made a special study of fractures of the articular processes, states that they rarely unite.

These clinical observations may be explained by the fact that according to the embryologist, Willis, vertebral bone is derived from the ectoderm from which tissues of higher differentiation and low degree of reparative ability have their origin. One need only mention the optic nerve, the nerves of hearing and those of the spinal cord as illustrations. It may be Nature's plan *that vertebral bone should have* a low degree of osteogenesis. For although it may not be advantageous from a surgical standpoint, yet for Nature's purposes, it is much safer than if osteogenesis were high, because when spinal bone is involved by disease or fracture,

it does not tend to pour out callus in excessive amounts and encroach upon the spinal cord which it serves to protect

These convictions regarding the low osteogenetic potentialities of vertebral bone were confirmed by my experiments in 1908 and 1909 when cubes of the same size of vertebral bone and ulnar bone from the dog were transplanted into muscle under identical conditions, after varying periods the ulnar bone showed unmistakable superiority in osteogenetic value

The tibia, with its derivation from the mesoderm, fortunately for the purpose of the surgeon, inherently has good osteogenetic potentialities and reparative power Insertion of a strong graft from this source is, therefore, preferable

The blood supply to the cross section of cortical bone is 25 per cent *via* the periosteum and 75 per cent *via* the marrow and endosteum In the case of flat or irregular shaped bones such as the vertebrae, this relationship may be somewhat changed, but it is approximately in this proportion, and, therefore, the ideal procedure would be to contact the graft generously with the interior of the bone of the spinous process, the whole central portion of which is cancellous This should be brought about with the minimum disturbance of the circulation to the bone into which the graft is being incorporated or inlaid It was with this consideration in mind that the inlay graft for the treatment of Pott s disease as well as other conditions of the bones and joints was conceived

Biological Influence of Bone Graft —In thirty years of usage of the bone graft in tubercular spines of all degrees of severity, both as to acuteness and extent of the disease, I have been increasingly impressed with the unusually favorable reaction or curative effect of fusion During this period in exhaustively studying a rapidly increasing series of cases by x ray and occasionally pathologically, the author has been much interested in the unusual reparative and curative influence exerted by the ankylosis secured by bone graft

I believe the amalgamation of diseased vertebrae with healthy ones on either side influences the repair of the diseased vertebrae at least in two ways, namely, increased stress with its stimulus to metabolism is thus brought to bear upon the undiseased portion of the involved vertebrae with complete immobilization of one vertebra to another, and the bony bridge produced by the graft acts as a vascularizing influence, bringing blood from the posterior part of the uninvolved vertebra to the posterior part of the diseased vertebral body, and thus to the diseased bone This autogenous graft is put into the split spinous process in intimate contact with the vascular system of the vertebrae under the most favor-

able conditions for vascularization of the graft and its linking up with the vascular system of the vertebra. The immediate and profuse vascularization *of a graft when inserted for any condition whatsoever has been a* most striking phenomenon.

The osteogenetic potentiality of vertebral bone is always diminished by tuberculous involvement. Furthermore, the osteogenetic potentialities *of different individuals vary within wide limits and are absolutely impos*sible to determine in advance, even at the operating table. For these

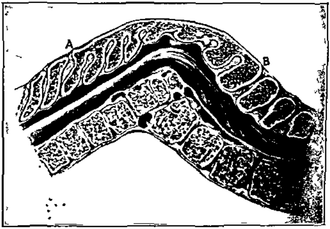


Fig. 28—An anteroposterior longitudinal section of a spine two years after the tibia bone graft had been implanted into its split spinous processes to ankylose the tuberculous infected vertebrae present between *A* and *B*.

The drawing was made from an actual specimen and represents the alteration which has taken place in the character of the graft and its bed.

The area *A* to *B* has been so changed that it presents the characteristics of a single bone with a distinct cortex enclosing cancellous bone structure throughout, or, in other words, it has become identical in its anatomical structure to the spinous processes to which it has become amalgamated.

This is a fortunate characteristic of the bone graft, *i.e.*, it adapts itself to its environment. From Albee, *Orthopedic and Reconstruction Surgery*, W. B. Saunders Co.

combined reasons, it is incumbent upon the surgeon to play the game as safely as possible, and to select not only an ample amount of bone in the form of a complete splint, but bone of the greatest known osteogenetic potentiality. To rely on the low osteogenetic potentialities of vertebral bone, particularly in the form of chips, is to gamble on getting a favorable outcome instead of being practically certain of it.

The autopsy findings of Professor T. Wingate Todd, Professor of Anatomy at Western Reserve University, in a case of Pott's disease, further demonstrate the osteogenetic potentialities of the tibial graft as used by the author:

"The case is *one of perfect* functional result from an Albee operation.

Where the splint is grafted into the spinous processes, there has been marginal erosion and proliferation of new bone precisely as in the repair of a fracture (Fig. 28). Where the splint lies embedded in soft tissues, no proliferation or change has taken place in the implanted bone, except that a modification of its texture has occurred indicating a living but inactive condition." [1]

A graft of living bone not only provides immediate mechanical sup-

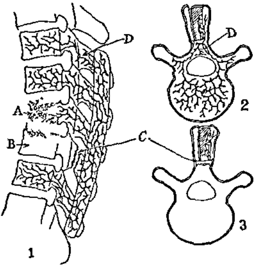


Fig. 29—Schematic representation of the supporting and vascularizing functions of the graft The section shows the side of the gutter on which the half spines are left intact (*D*) The circulation in the graft has linked up with that of the healthy vertebrae and with one diseased vertebra (*A*) through the intact half spine, diseased vertebra (*B*) fails to obtain immediate mechanical support or revascularization because the half spine has been fractured (at *C*) and has not reunited *This is illustrated to show the disadvantage of fracturing the second half either by accident or by design*

port and added osteogenic power to promote ankylosis, but also acts as a vessel-conducting scaffold from each spinous process to the next and from the unaffected ones to those whose circulation might be impaired by the effect of the tuberculosis on the blood supply; a diagrammatic representation of this is shown in the accompanying illustration The renewal of the blood supply I have always considered the first step in union, whether in the treatment of pseudarthrosis, the arthrodesis of a joint or the fusion of spines That the graft lives and increases in size in accordance with Wolff's law has been clearly demonstrated again and again (Fig. 29).

Whether the graft has any other effect than that brought about by its immobilizing influence cannot be stated It would seem reasonable to

[1] *Am J Surg*, Oct, 1935, 30 64

attribute the unusual success of the method, in part at least, to the linking up of the cancellous circulation in each affected vertebra with that of its neighbor, and through the graft, with that of the healthy vertebrae adjoining the affected area, as shown in the illustration. At least, it is difficult to account for the phenomenal results on the basis of immobilization alone, although it is realized that complete immobilization cannot be effected in any other way.

An important consideration is the length of time required for an operation and the shock occasioned by it. An operation that consumes little time and induces comparatively little shock may obviously be undertaken when the surgical risk is not of the best. The bone graft operation may be completed in as little as nine minutes in a favorable case, if one's operating team is thoroughly familiar with the routine and the special instruments required. The technic does not require excessive retraction and there is no necessity to operate more or less blindly in regions difficult of access. The small amount of shock produced by this operation is due to its simplicity and consequent shortness of duration as well as the minimum amount of retraction and traumatization of tissue it entails.

Indications and Contraindications for the Operation.—My practice is to operate on any patient at any age provided the surgical risk is good. The surgical risk in this instance depends on several factors:

(1) *General Condition of the Patient.*—I have already discussed the question of shock. If the surgeon is reasonably skillful and works in suitable surroundings, he may consider the bone graft operation safe if the patient is a good risk for any major operation.

Paraplegia, paravertebral and psoas abscesses provide an additional indication for the operation.

High temperature due to secondary pyogenic infection is a contraindication to operation. The bacteriemia must be allowed sufficient time to subside; a transfusion of blood may help. Pyrexia, due solely to the tuberculosis, is not a contraindication to operation.

(2) *Multiple Lesions.*—The presence of tuberculous foci elsewhere has often to be taken into consideration in determining operability. I have frequently observed, especially when the focus was in the kidney, testicle or epididymis, that the spinal lesion went on to a successful issue following operation, although the general resistance of the patient was insufficient to prevent the progress of the second focus or foci either to the point of destruction of the affected organ or to the necessity for its extirpation. I have observed the same favorable results after operations on monarticular joints in the face of tuberculosis elsewhere. The presence

of a second tuberculous focus, therefore, even if it is progressive, does not contraindicate the operation

(3) *Field of Operation*—The presence of sinuses is not a formidable obstacle unless they are situated near the spinous process or in the field of operation Fortunately, the anatomic planes of cleavage are so placed that it is rare for a cold abscess, or ichor pocket to point in the region of the spinous processes They may point close enough in the loin to the field of operation to demand special care The skin must be thoroughly prepared and the sinus sealed with a collodion tampon before the operation is begun The indication for operation is increased when an abscess or sinus is present

In seven cases, I have unexpectedly encountered an ichor pocket deep in between the spinous processes In none of these did it interfere with the union of the graft or the course of convalescence

(4) *Age of the Patient*—The bone graft operation has been more readily accepted by the profession in adults than in children although in recent years one finds the pendulum definitely swinging toward operative treatment for children, partly as a result of increased study of late end results by those who opposed operative treatment in children It has been held that, since the bones in a child are smaller and not fully developed the operation should be postponed My position is that advantage should be taken of the speed and safety of the operation to afford the child the aid of ankylosis at the earliest possible moment

In a case of acute progressive spinal disease in the child, one often observes excessive hinge motion at the center of the kyphosis accompanying respiratory movements This indicates that the underlying vertebral bodies have disintegrated the respiratory thrust has been concentrated into the area left without the immobilizing support of the intact vertebral bodies A vicious circle is set up the greater the mobility the more rapid the destruction and destruction increases mobility The bodies melt away progressively

There is no room for argument in such cases It is clear that the excessive motion must be halted by direct local influence and the destructive process must be checked as soon as possible It is equally clear that frames and braces, as the only treatment, cannot be expected to meet such demands Operative treatment is decidedly indicated

If a continuous bone graft bridge is inserted at the point of greatest mechanical advantage, namely, the split distal portion of the spinous processes, the bony elements at the site of the kyphosis instead of being weakened, are supported, and the minute the sutures are tied, immobility is favorably influenced (Fig 30)

Allison makes the rather surprising statement that "in children, the time element may be largely disregarded." I feel, on the contrary, that it is a sort of a divine right of childhood to be able to run and play at the earliest possible moment, and that only by doing so, can normal growth and development, mental and physical, be assured.

The prognosis following such an operation is very promising as regards relief of symptoms and, in suitable cases of children, decrease of the deformity. Results in incipient stages in adults have been exceedingly gratifying; relief of symptoms and arrest of the degenerative process have usually occurred in the more chronic cases. In refutation of the contention made by some that the bone graft operation in children pro-

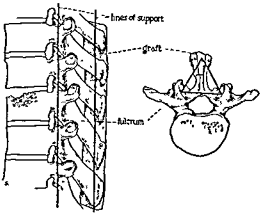


Fig 30—The mechanical advantage of the inlay graft when placed in the tips of the spinous processes. The broad fulcrum through the lateral facets is indicated; the location of the graft, and the leverage action of the spinous processes.

duces deformity and that healing by cartilage takes place, I have obtained abundant evidence from clinical and roentgenographic observations over a period of thirty years, that the growth of the graft keeps pace with the rest of the spine in these cases. It should also be remarked that any tendency to the development of lordosis in these cases of bone graft fixation is counteracted by the tendency of the spine to curve in the opposite direction (kyphosis). The outlook is, of course, strongly influenced by the postoperative regimen of the patient, which should include plenty of fresh air, and sunlight, abundant nourishing food and regulated periods of rest.

Inlay Bone Graft Technic.—In acute cases with sharp kyphosis the patient is put on the convex Bradford frame, or in a possibly corrective plaster jacket, for a varying length of time for correction of the kyphosis. The graft should hold the spine either in the position of deformity to

which the disease has progressed, or in the position of correction attained prior to operation

I have described several variations of the technic, but I now use two methods almost exclusively · the single-graft inlay and the bent-shingle method, or the "bundle of reeds" The operation is carried out with the

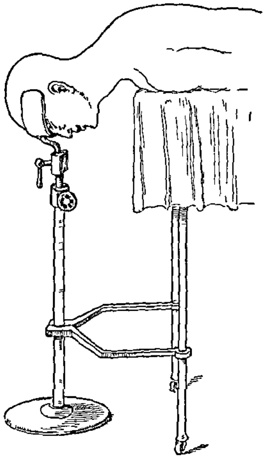


Fig 31.—Position of patient and adjustment of head rest for insertion of spinal graft for *Pott's disease of cervical region* From Albee, *Orthopedic and Reconstruction Surgery*, W B Saunders Co

patient prone; if in cervical region, with head hanging over the table and supported by a special rest (Fig 31).

The exposure and preparation of the spinal gutter or graft bed is the same in all cases The incision is semilunar, usually about 6 to 8 inches in length, it begins well above the site of the lesion, makes a wide sweep to one side of the midline, ending well below the diseased area The curve allows the engrafted structures to be kept at a distance from the

incision and to be protected from contamination in the event of skin or suture infection.

When the skin flap is dissected and reflected, the tips of the spinous processes lie directly exposed. Hemorrhage, usually slight, is best controlled by compression with gauze wrung out of hot saline solution.

With a scalpel, the supraspinous ligament is split into halves longitudinally over the tips of the spinous processes. The interspinous ligaments are treated likewise. The spinous processes of the affected vertebrae and of two above and two below in the dorsal region (only one above and below in the lumbar region) are split *in situ* in halves longitudinally almost down to the neural arches. I employ a special broad thin osteotome (Fig. 12); the motor-saw is not satisfactory as it is too difficult to guide. After one process has been split, I anchor one edge of the osteotome in the cleft so as to guide the other edge while it splits the next process above or below. Great care must be taken to fracture only one of each pair of spinous process halves; if both halves are fractured, the continuity of blood supply through the graft into the vertebral body is interfered with, immediate immobilization of that particular vertebra is not affected and there is the risk that, because of low osteogenic power, reunion of the fractured spine may not occur and the vertebral body will not receive that mechanical support and vascular rehabilitation which the operation is designed to provide. The gutter for the graft must be bounded by a row of fractured half-spines on one side, and a row of unfractured half-spines on the other, with their split-imbedding ligaments.

The single graft from the tibia must be long enough to cover the entire length of the gutter, including that in the intact vertebrae, as already specified. It must be strong enough to stand the strain to which it will be subjected, and its diameter should be about one-fifth that of the tibia.

The shaping of the single graft can be accomplished only to a limited degree. By cutting the upper and lower portions of the graft from the antero-internal surface of the tibia at an angle to the axis of its middle portion, which crosses the tibial crest, one can secure a graft with a greater or lesser curve; but the tibia is not wide enough to provide a single graft suitable for more than a moderate kyphosis. In more extreme cases the "bundle of reeds" technic is followed. If the operation is undertaken as early as it should be, the kyphosis will not be too great and a moulded tibial graft can be used (Fig. 32).

The length and shape of the required graft are determined by calipers and a flexible probe applied to the gutter bed; the latter is protected by a hot saline compress tightly packed, awaiting the preparation of the graft (Fig. 33).

Removal of the Graft—The patient being in the prone position, the prepared leg is raised and flexed to an acute angle with the thigh A skin incision is made along the anteromesial surface of the tibia for the removal of the graft, and so placed that its closure will not bring the skin sutures over the bone cavity produced by removal of the graft The skin is dissected from the periosteum and the muscles freed from their attachments to the outer side of the tibial crest

The size and thickness of the graft depend upon the segment of the spine to be immobilized and the amount of strain required of the graft In general, it should include the total thickness of the tibial cortex (periosteum, endosteum and marrow), and its width should be three to four times this amount (about 1/5 diameter of tibia)

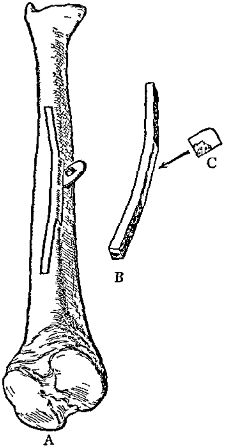


Fig 32—*A* saw cuts in the antero-internal surface of the tibia for obtaining a moulded graft *B* a longitudinal view and *C* a cross section of the same at its strong central portion From Albee *Orthopedic and Reconstruction Surgery* W B Saunders Co

The graft must be long enough, in most instances, to include the spines of two healthy vertebrae above and two below the diseased area It must be constantly borne in mind that on account of the natural obliquity of the spinous processes in certain regions (particularly the dorsal), the fact that their tips are well below the horizontal planes of their corresponding bodies (x ray appearance) may mislead the operator into cutting the graft too short to include the requisite number of healthy spines or placing it too low in the spine A satisfactory lateral radiogram should always be obtained, not only to confirm the diagnosis but to serve as a guide in inserting the graft A small piece of lead is fastened with a tiny strip of adhesive to the skin over the most prominent spinous process The skin beneath is marked with lunar caustic for the surgeon's guidance

With the moulded probe serving as a pattern rod, the required graft

is outlined on the periosteum with a scalpel. The central three-fourths of the anteromesial surface of the tibia is usually selected.

At this stage, one must decide whether the spinal conditions are such that a slightly curved graft can be inserted. A perfectly straight graft is never employed as there would be danger of its slipping out of the spinous processes at its end. The graft should bear no corrective stress at the time of its insertion. If the kyphosis is extreme, one must provide for curving the graft; and this may be done in one of three ways: (1) cutting a curved graft, which is always preferable if possible (Fig. 32); (2) leaving each end of the graft solid for a short distance, but making long vertical incisions close together through its central portion so that it resembles a "bundle of reeds" which will bend out as needed (Fig. 37); (3) *bent shingle grafts.*

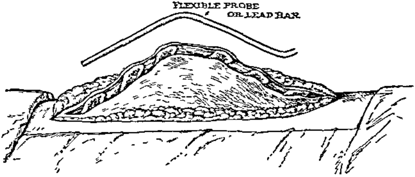


Fig 33—The flexible probe bent to conform to the spinal kyphosis and used as a pattern in removing the curved graft from the antero-internal surface of the tibia. From Albee, *Orthopedic and Reconstruction Surgery*, W. B. Saunders Co.

If the graft is to be nearly straight, it is best removed from the crest, the anteromesial surface being encroached upon to furnish the curve required. If it is to be moulded for a moderate kyphosis, which is by all means the one most frequently used, *the central or fulcrum portion of the curved graft should include the crest of the tibia and from this portion each end is cut obliquely upward and downward on the anteromesial surface of the bone* (Fig. 32). The advantage of this lies in that the dense thick cortical bone at the tibial crest forms its central or fulcral portion of the graft which constitutes its strength. In order that the pattern of the graft may be moulded to conform to the shape of the spinal gutter-bed after correction, the probe is bent into the clefts of the split spinous processes while manual pressure is exerted on either side over the lateral masses. Sharp angular kyphoses, and those of short duration, particularly in children, are amenable to varying degrees of correction (Fig. 34).

To Obtain the Graft—The tibial cortex is cut through to the marrow cavity, with a motor single circular saw (1¼ inches in diameter (following the periosteal outlines of the pattern; this includes a saw-cut just to the outer side of the tibial crest and at a right angle to the one previously made on the anteromesial surface This cut must be made the whole length of the graft, if nearly a straight one; and, if a moulded one, only to include the middle or fulcral portion At either end, beyond this central or crest portion, the graft overlies the marrow cavity; the saw-cuts, therefore, need only be made on the anteromesial surface to free the graft.

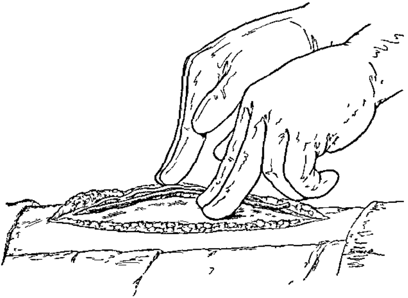


Fig 34—Method of applying force to straighten spine, at the same time that the contour of the corrected kyphosis is obtained with flexible probe for purpose of pattern for removal of graft from tibia See Fig 32 From Albee *Orthopedic and Reconstruction Surgery*, W B Saunders Co

The graft is freed by cross cuts at either end, made with a very small motor-saw. It is then loosened and pried out by a thin osteotome introduced into the longitudinal saw-cuts

The cutaneous incision in the tibia is closed by an assistant with a continuous suture of No o plain catgut, and the wound properly dressed, while the operator proceeds at once to implant the graft

Inlaying the Graft.—When the graft is a moulded one, it is held in place by a strong suture of kangaroo tendon, passed through one-half of the split supraspinous ligament at one side of the gutter, thence up over the graft at its central portion and cut through the opposite split half of the supraspinous ligament. When this suture is tightened and tied, the

two halves of the split supraspinous ligament are approximated over the central portion of the graft. The extremities of the graft are then secured in like manner. The sutures should be passed deeply enough to get a firm hold upon the ligament and close to the spinous processes (either above or just below them) to obtain the most intimate contact possible between the graft and the raw surfaces of the bisected spinous processes (Fig. 35).

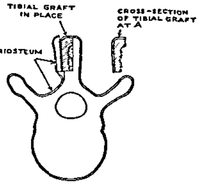


Fig 35—Method of placing graft so that its marrow surface will contact marrow of intact half of spinous process.

In some instances, in order that the supraspinous ligament may yield and completely cover the graft, it is advisable to place the sutures in the ligament midway between the spinous processes or at a varying distance to the side of them (Fig. 36). This ligament in the lumbar region especially (particularly in adults) may be so dense and tense as to require incision of the vertebral aponeurosis on either side just external to the line of sutures, thereby allowing it to be drawn together to cover over the thick graft.

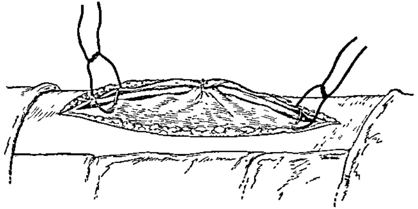


Fig. 36—Moulded graft for Pott's disease in place with the kangaroo tendon sutures in process of being inserted. From Albee, *Orthopedic and Reconstruction Surgery*, W. B. Saunders Co

Before the ends are fixed in position, their sharp corners are removed by rongeur forceps and the fragments placed about and under the graft ends before the latter are secured with sutures. The removal of these bone fragments from the ends of the graft on its posterior edge surface with a rongeur cutter causes it to be roughened so that it is better held

and thus prevented from springing backward by the ligaments sutured over it. These fragmented particles furnish added foci for bone proliferation and enhance the amalgamation of the graft ends and the contacted spinous processes. The rest of the graft is then secured with kangaroo tendon sutures placed at intervals throughout its length

If the graft has been cut on the curved pattern, it must be placed on edge in its bed in order to fit the kyphos; its periosteal surface lies to one side and its marrow surface lies in contact with the side of the gutter formed by the unfractured halves of the spinous processes, the *periosteal* surface contacting with the fractured halves The *endosteal* (marrow) surface, which is the more actively osteogenetic, is thus in contact with the more virile unfractured half of its host

The curved graft is secured in a manner very similar to the straight graft

The "Bundle of Reeds" Technic.—For a very sharp angular kyphosis, or one of great extent, it would be manifestly impossible to cut from the tibia a graft of sufficient angularity, and the outer table of the ilium may have to be resorted to I have devised the following procedure, whereby a series of thinner tibial grafts, overlapping each other, conform to the kyphosis and by combined strength approximate the same immobilizing support as the single graft.

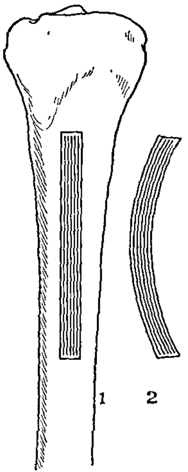


Fig 37—"Bundle of reeds" technic See page 65 Intermediate cuts fall short of transverse saw-cuts so that graft remains intact and greater flexibility is obtained

The graft bed in the spinous processes is prepared as already described on page 60 After the exposure of a sufficient area of the central portion of the anteromesial surface of the tibia to provide a graft of the requisite length and diameter, longitudinal cuts are made with the twin saws approximately one-half inch apart, down to the marrow (Fig 37). With the single saw, cuts are made between these two, down to the marrow, so as to provide four very thin strips These intermediate cuts fall somewhat short of the original two, so that, when the latter are jointed

by a transverse cut at each end, the entire graft is lifted out in one piece, with a bridge across each end where the intermediate cuts fell short. This flexible graft is then placed edgewise in the spinal gutter, so that one end of it is in contact with the least favorable end of the graft bed. It is held there with kangaroo sutures through the split supraspinous ligament. Having been firmly fixed at one end, the graft is now grasped in a clamp and bent into the gutter and held with interrupted sutures of kangaroo tendon as the moulding progresses (Figs. 38, 39). The author has found

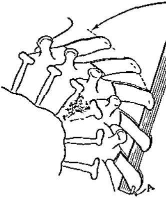


Fig. 38—Flexible graft placed edgewise in spinal gutter.

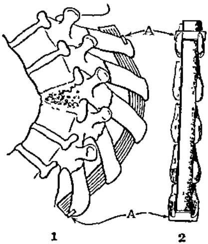


Fig. 39—Fixation of "bundle of reeds" graft by bone chips. 1, lateral view. 2, posterior view. Showing the "bundle of reeds" in split spinous processes fixed in place by bone chips at *A*.

this method preferable to making a series of transverse cuts as formerly practised (Figs. 40, 41) or the overlapping shingle method.

Errors in the Use of the Bone Graft.—During the last thirty years, I have had occasion to observe the methods of others in applying bone grafts. Sometimes these observations were made while the graft was being applied; sometimes at longer or shorter intervals after the operation. The conclusion has been inescapable that no operation is so badly misunderstood and so incorrectly carried out as that of applying a bone graft to the spine. Such errors are difficult to explain since the operation is not, as a rule, attempted except by skilled surgeons who might be expected to interpret accurately the description of an operative procedure. In one University Clinic, the x-ray showed that the graft had been properly placed in only two cases out of nine.

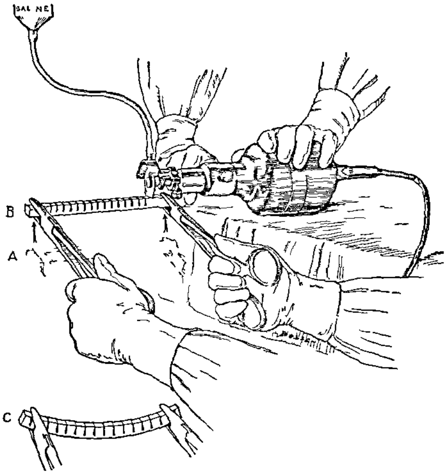


Fig 40.—Method formerly practiced by author for bending the graft
A the manner of holding the graft while making the transverse saw-cuts to increase its flexibility
B transverse saw cuts at equal intervals and over three quarters through the diameter of the graft on its marrow surface
C testing for the desired amount of curve in the graft obtained by making the transverse saw cuts before applying it to the kyphosis of the spine See Fig 41 From Albee *Orthopedic and Reconstruction Surgery* W B Saunders Co

The errors may be classified as follows

(1) Graft too short
(2) Graft of too small diameter and hence too weak
(3) Graft in faulty position
    (*a*) Not engaged in the gutter of the spinous processes but posterior to it
    (*b*) In the wrong processes
(4) Spinous processes lacerated and destroyed in sawdust by unwise use of the motor saw

The last error is avoided by recourse to the broad thin osteotome devised for the purpose. The presence of dense ligaments makes the use of the motor-saw awkward, and subject to the risk of wholesale lacera-

Fig. 41.—Lateral roentgenogram of a spine of a man twenty-two years old, which is illustrative of the extreme degree to which an adult tibial bone graft (*A, C, B*) can be bent. *C* indicates the saw-cuts in the marrow side of the graft From Albee, *Orthopedic and Reconstruction Surgery*, W B Saunders Co.

tion of all structures. Moreover, the bone dust lost in the use of the saw cannot be well spared from the spinous processes. In the dorsal region, especially, the use of the saw is not practicable.

Postoperative Treatment.—When the child is under ten, I keep the

patient in bed for a minimum of from six to eight weeks according to progress (Fig 42) I apply Taylor s spinal brace for a period of four to six months or more as indicated In cases of paraplegia, the patient remains recumbent until the paraplegia disappears When a strong shaped graft is used in the adult recumbency on a fracture mattress is maintained for six weeks No other support and no brace is usually em ployed Throughout the whole course, a regimen is established suitable

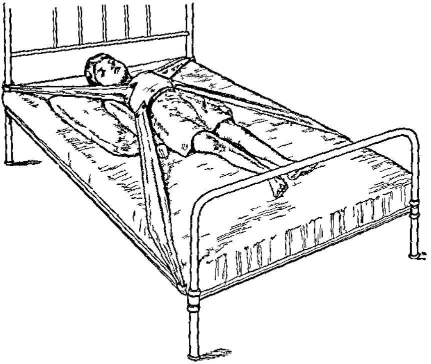


Fig 42 —Method of fixat on in bed after the bone graft implant for Pott s disease has been applied in a ch ld From Albee *Orthoped c and Reconstruct on Surgery* W B Saunders Co

in every particular for a patient with tuberculosis The author has been able to verify the permanency of the healing process induced by the bone graft spine fusion in a large series of cases up to 26 years after opera tion [2] (See Figs 43 47)

Girdlestone has stated that if bone grafting is done, the door is closed for future laminectomy This is an erroneous statement in that I have performed laminectomy at varying periods following a bone graft inser

[2] For a stat st cal analysis of results the reader is referred to the *Journal of the American Med cal Associat on* May 10 1930 The Bone Graft Operat on for Tuberculosis of the Spine—20 Years Experience

Fig 43—Roentgenogram taken ten years after fusion of the spine by bone graft for Pott's disease Note mechanical advantage of secondary column of bone formed by the bone graft in resisting advancing kyphosis.

tion into the spinous processes. To be sure, the laminectomy is unilateral, but it affords a very excellent decompression of the spinal canal.

He further states that he puts in two tibial grafts and accomplishes the laminectomy at the same time by cutting out the spinous processes and the laminae at the region in which he wishes to produce decompression.

The grafts are then anchored into at least two vertebrae on each side distal to the area of laminectomy. I wish to emphasize that it is extremely rare that laminectomy becomes necessary. In thirty years of experience in over 2,000 cases, I have found it necessary to resort to laminectomy in only seven. The immobilization brought about by the graft, and the cure of the tuberculosis with subsidence of the pachymeningitis clears up the paraplegia in the great majority of cases.

I prefer to split the spinous processes in the center to put in a strong graft. This allows the most ideal conditions for the complete and early vascularization of the graft from two sides. When the double graft is put in, there are islands of bone (denuded spinous processes) between the grafts which are largely cut off from blood supply. I think from an idealistic standpoint, the single massive inlay graft is preferable, although, no doubt the double graft gives very excellent results.

Fig. 44.—Bony ankylosis of lumbosacral joint induced by bone graft fusion twenty-one years previously. Note maximum hypertrophy of graft at point of greatest stress in accordance with Wolff's law.

Girdlestone's Technic of the Combined Laminectomy and Graft Operation

The incision is slightly to the left side so as to keep the scar away from the spinous processes and in order that the motor saw may be used unhampered by retractors on the surgeon's side. The skin and subcutaneous tissue are lifted from the deep fascia and reflected away from the surgeon beyond the line of spinous processes; the skin edges are closely and smoothly covered with fine towels.

Then an incision is made on to the apex of each spinous process and carried by a dip of the point of the knife through the interspinous ligaments over an area covering the three spines of the laminectomy area, two spines above and two below. As the line of processes is often deranged by caries and as it is best to make the incision run exactly over the apex of each process, it is helpful to define each process as the incision reaches it by gripping it between the points of a pair of dissecting forceps held in the left hand. The motor saw is then taken and two incisions are made into each spinous process forward and slightly outward to the right and to the left. They start in the knife cut and separate a thick flake of bone from the spinous process on each side. When each process has been dealt with in this way, the saw is laid aside and an osteo-

tome, 1½ inches wide, is used to complete the separation of the lateral flakes of bone from the central part of each spinous process, and then carry these flakes outward, together with the periosteum of the bases of the spines and laminae. I use an osteotome very broad so that it cannot possibly get between the laminae, and sharp so that it can be used gently without disturbing the carious centra. Each time *the osteotome travels*

Fig. 45—Excellent result 26 years after spine fusion for Pott's disease of lumbar vertebrae at two foci Patient is a seaman engaged in the most strenuous type of activity. Note absence of deformity—amalgamation in two locations of formerly diseased vertebrae by osseous union and firm incorporation of bone grafts with the trabecular system of the spinous processes

outward, the space between it and the spinous process is packed with gauze so that by the time the upper end is reached there is a thick packing all the way up that side. The *other side is treated in the same way. It should be said that the laminae are only* fully exposed where they are to be removed. In the case of the two spines above and below, the displacement of the flake of bone and periosteum does not go *beyond the base* of the spinous process.

The laminectomy is then performed. It is essential to make the laminectomy opening of full width and long enough to relieve all the pressure present or at all likely to occur. I do not think I have ever had to remove more than three laminae for Pott's paraplegia.

I do not open the dura but "seek' gently around it, and sometimes evacuate a mass of debris from the side of the theca

Next comes the graft The length and shape of the grafts required are recorded by bending a probe, and two Albee grafts about 3/8 of an inch wide are cut from the tibia These can generally be straight If so, they are put in with the periosteal surface

FIG 46

FIG 47

FIGS 46 and 47—A *very acute case of tuberculosis of lumbar spine—three months after* bone graft was inserted The excellent spinal function is shown by Fig 46 which illustrates static posture, and Fig 47, flexion posture From Albee *Bone Graft Surgery,* W B Saunders Co

deep that is with the smooth limiting membrane turned toward the theca If the spine is straight or only moderately kyphotic, this gives plenty of clearance at the site of the lesion, because the grafts are carried fairly high up on the spinous processes above and below If on the other hand there is much angular curvature one of two methods must be used

1 *Shaped grafts,* to fit the angulation This means using the broadest part of the tibia, and not sparing the crest 2 *Flexible grafts*[3] When the grafts are firmly in place, and one has made certain that there is plenty of space between their deep surface and

[3] This refers to the author's bent in graft or to the "bundle of reeds" technic (see page 65)

the theca, the edges of the supraspinous ligament, carrying with them the lateral flakes of bone from each spinous process, are sewn together over the grafts. Just previous to this, if there are one or more prominent spinous processes, they are nipped across with bone-cutting forceps and bent under the suture line. This makes for comfort and safeguards the skin from pressure. The operation is completed by suture of the skin of the back and the leg.[4]

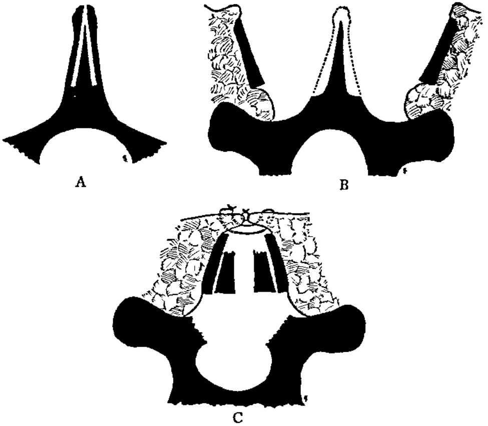


Fig 48.—Girdlestone's technic.
A, motor-saw cuts into a spinous process.
B, state of affairs after reflection of osteoperiosteal flaps in the area of the laminectomy
C, grafts bridging defect left by laminectomy, with their lateral osteogenetic hosts. (By courtesy of Prof G R. Girdlestone.) From "The Operative Treatment of Pott's Paraplegia," *Brit. J. Surg.*, July, 1931, 19:121-141.

Technic of Hibbs' Operation for Relief of Pott's Disease

A longitudinal incision is made directly over the spinous processes through the skin, supraspinous ligament and periosteum to the tips of the spinous processes. The periosteum is split over both the upper and lower borders of the spinous processes and the laminae, and stripped back from them to the base of the transverse processes. The spinous

[4] G. R. Girdlestone, *Brit. J. Surg.*, July, 1931, 19:121-141.

processes are then transposed after partial fracture, so that they make contact with fresh bone, the base of each with its own base and the tip with the base of the next below The adjacent edges of the laminae being absolutely free from periosteum, a small piece of bone is elevated from the edge of the laminae and placed across the space between them, its free end in contact with the bare bone of the laminae next below it The lateral walls of the periosteum and the split supraspinous ligament are brought together over these processes by interrupted chromic catgut sutures The skin wound is closed by silk, and a steel brace is applied with the space between the uprights increased somewhat at the site of the wound so as not to make pressure on it In some cases the gaps in the periosteum removed from the spinous processes and laminae have been closed

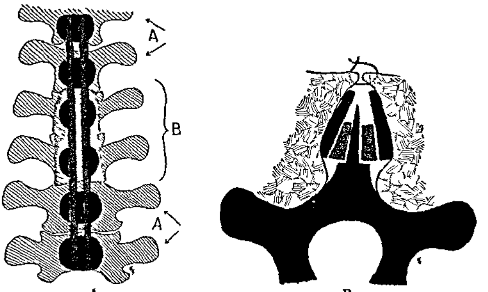


Fig 49 *A*—Diagrammatic coronal section of spinous processes and graft, with vertebrae and area of laminectomy indicated *A*, grafts well supported on spines, *B*, area of laminectomy

Fig 49 *B*—*Showing grafts as supported on spines above and below area of laminectomy*

(By courtesy of Prof G R Girdlestone) From "The Operative Treatment of Pott's Paraplegia," *Brit J Surg*, July, 1931, 19 121-141

by suture, thus establishing at once a continuous wall Hibbs advised that rest in bed be absolute for eight to ten weeks, that during the next four weeks sitting-up be permitted, and at the end of the twelfth week walking The brace is continued for another month and then removed for a part of each day until gradually it is left off entirely. In the case of children under 5, it is to be worn for six months [5]

The Hibbs' method of fusion followed the lines of my first attempts, but Hibbs secured more bone for fixation by including the laminae and articular facets as well as the spinous processes While the bone graft method and the Hibbs' method both have their advocates and both bring about fusion, I have been convinced that the Hibbs' operation may de-

[5] R. A Hibbs, *J Am M Ass*, 1918, 71 1372


IV thoracic vertebra
XII thoracic vertebra
a
3


c
4

mand a higher degree of osteogenic power than the vertebral bone can be expected to supply Since there is no way of foretelling how high this power may be, and since in tuberculosis it may fairly be expected of being even lower than it normally is, I have considered it wise to assume that the osteogenic power was at so low an ebb as to demand augmentation by the implantation of bone of demonstrably higher osteogenic power, such as that available in the tibia Again, from a mechanical standpoint, it must be realized that fracturing the spinous process at its base disturbs important ligamentous and muscular attachments that are vital in resisting a tendency to increasing kyphosis in the dorsal spine In the bone graft operation, not only are the posterior arms of the lever retained, but further deformity prevented by their permanent fusion to each other, and the formation of an additional column of bone that is mechanically designed to resist further increase of deformity

The biological influence of the graft in augmenting the blood supply to the diseased area by opening up new avenues of approach from healthy vertebra above and below the lesion *via* the spinous process of the diseased vertebra, must be considered when a spinal fixation operation is contemplated Small chip grafts are not apt to lay the groundwork for the uninterrupted vascular scaffolding available in a stout tibial graft, which after implantation is rapidly permeated by young capillaries from the surrounding tissues My first experience with chip bone grafts was in my operation to produce arthrodesis of the hip particularly in osteoarthritis After denuding both head and acetabulum of all their hyaline cartilage, numerous chip grafts were placed about the periphery of the joint This work was published thirty years ago Because of the experience gained at the hip and many other applications, I have abandoned the chip graft entirely as untrustworthy For supplemental grafts, I employ the sliver graft exclusively (see Introduction)

Again, the operating time must be considered a drawback inasmuch as the detailed procedure generally consumes 60 to 90 minutes A minor point, but of clinical importance, is the fact that the x ray may not be of any assistance in determining whether or not fusion has been obtained The superimposition of the shadows of numerous potential areas of arthrodesis tend to obscure the picture, whereas the graft lends itself to x ray study in establishing progress and permanency of fusion

The incidence of failure of fusion or pseudarthrosis following Hibbs' operation in recent publications, although reported for other conditions, is yet surprisingly high, ranging from 21 per cent in attempting a lumbo sacral fusion for low back pain (Kimberly, N Y Orthopedic Dispensary and Hospital, New York) to 47 per cent in scoliosis (Brogden, Rup

tured and Crippled Hospital, New York). Kimberly commented: "The high incidence of pseudarthrosis as well as the difficulties encountered in trying to effect a repair is discouraging." Brogden was of the opinion that "the use of an autogenous bone graft assures a more solid fusion *than does the Hibbs' technique alone.*"

SCOLIOSIS

The history of corrective treatment of structural scoliosis presents one of the gloomiest chapters in orthopedic practice. The result of treatment in a given case is always problematical, whatever the conservative method employed.

The scoliotic deformity, being produced by the synchronous interaction *of* (*a*) *abnormal* postures, (*b*) their fixation by the constant operation of the fundamental cause, (*c*) increased by the superimposed weight of the upper trunk, shoulders, head, and neck and (*d*) loss of *tone of the* spinal muscles, local treatment must be directed at breaking simultaneously all links in this vicious chain of events. This corrective treatment is best applied in the following forms: (1) Maintenance of the general health. (2) Daily periods of recumbency. (3) Postural methods to give the patient an educated muscle sense to procure instinctively correct attitudes. (4) Exercise, both active and passive, supplemented by massage. *If these methods, severally or collectively, after being given a fair trial,* are unavailing, resort is had to: (5) Rapid correction by (*a*) manipulation and fixation, supplemented by (*b*) operative correction by the strong inlay bone graft in selected cases, to aid in maintaining the correction used in conjunction with a turnbuckle plaster cast. (6) Palliative spinal support in intractable cases.

Paralytic Scoliosis.—The general rules of treatment applying to all *types of infantile paralysis should be carried out during the initial febrile* stage, namely, restraint in bed, or on a gaspipe frame to restrict motion of the vertebra of the involved area of the spine. Following the febrile stage, external supports such as plaster of paris corsets and metal frame braces, self-suspension by the Sayre apparatus, etc., should be applied together with corrective gymnastic exercises until no further improvement can be attained, thus indicating that the paralysis still persists and *residual spinal deviation is a result of permanently destroyed* motor-nerve cells.

In severer cases of this type, it is difficult to maintain correction of this spinal deviation by any external appliance because whenever the patient assumes the erect posture, the spine slumps into an S-curve inside the

brace due to lack of muscle support This difficulty in maintaining correction by any external support is due to a combination of the following factors

(1) Large size of the thoracic cage (2) Its constant movements (3) Its ever changing volume under the influence of respiration (4) The fluctuation in degree of distention of the abdomen and its contents (5) The location of the spine in the extreme posterior portion of the trunk (6) The physical impossibility of immobilizing externally individual vertebrae, one with another, on account of the aggregation of 24 moving vertebral bodies each a unit of relatively small size

In this instance, on account of the unbalancing of muscle forces and the marked tendency of the deformity to relapse, it is impossible to maintain a general alignment of the vertebral segments

After a lapse of two years, it devolves upon the surgeon to decide whether the muscle weakness and the resulting curvature are sufficient to warrant the implantation of the more corrective and trustworthy bone graft support

Author's Technic of Operation—A plaster of paris bed with firm lateral walls should be moulded, before the operation, to the back and sides of the patient's trunk, and allowed to harden while the patient is held in the corrected position This plaster splint is then removed and laid aside until the operation has been completed The field of operation on the back as well as the leg, is prepared by the iodine method Six to eight spinous processes, as the case may be, at the apex of the most acute curve are laid bare on the convex side by a curved skin incision similar to the skin incision described in the bone graft operation for Pott's disease The muscles and ligaments over the tips and between the spinous processes are split into approximately equal halves with a scalpel The spinous processes are split longitudinally into halves and at the same time one half is set over to give room for the graft With flexible probe and calipers the contour and length of the desired graft are determined while the spine is forced manually by the surgeon and his assistants into the maximum of correction The tibia is flexed on the thigh and its anterior crest and antero internal surface laid bare The flexible probe pattern is applied to this exposed tibial surface, and the desired graft is outlined in the periosteum with a scalpel, its length being determined by the previous measurement with the calipers or flexible probe The motor saw is then made to cut along the periosteal outline and the graft is removed, including the full thickness of the cortex at the ends and crest at its central portion, and placed in its bed already prepared between the

halves of the split spinous processes. While the patient is held in the corrected position, the ligaments and muscles are drawn over the graft with interrupted sutures of heavy kangaroo tendon. This graft must be of great strength, especially at its central portion and be suited to the size of the patient and mechanical demands. In the adult, the graft at the central portion should have diameters of at least ⅝ inch from the crest each way so as to include the antero-internal and antero-external cortex. A strong tibial bone graft implanted into the spinous processes serves the surgeon as an internal lever and splint by which an unusual amount of the scoliotic deformity can be corrected at operation (Figs. 51-52). It also, by virtue of its internal splintage, inhibits the further

Fig. 51.—Paralytic scoliosis. See Fig. 52.

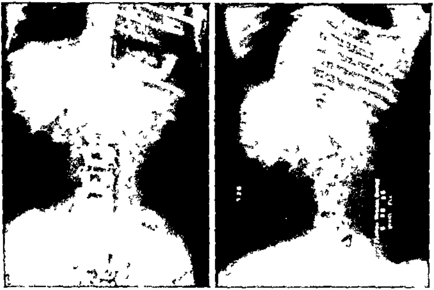
Fig. 52—Four months after spine fusion with tibial graft showing permanent correction of curvature.

increase of the lateral deviation, and its amalgamation into the spinous processes of several of the vertebrae in the most pronounced portion of the curvatures prevents further rotation of the vertebrae upon themselves. The graft splint also serves at operation as a lever enabling the surgeon to diminish the rotary deformity.

The patient is bandaged into the plaster of paris bed, previously prepared. Recumbency in this plaster bed is maintained for ten to twelve weeks. Following the immediate postoperative fixation, a well-moulded plaster of paris jacket or corset brace is applied to those cases which need further support supplemental to the graft. In some cases, temporary external support is necessary because of the unbalanced muscle pull of the spinal and abdominal musculature and the strong tendency to a

relapse of the deformity above and below that portion of the spine fixed by the bone graft.

Idiopathic Scoliosis.—Treatment by corrective medical gymnastics is rational therapy in early idiopathic cases. Curvature is overcome by strengthening, not undermining, the mainstays of the spine. When braces are employed for this purpose, the muscles, tendons and ligaments are weakened by suppression of the stimulus of function. When the brace is



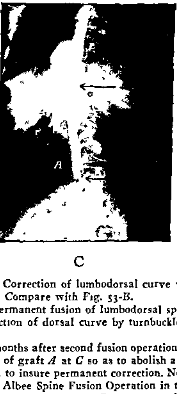
A B

Fig. 53.—*A*, left. Patient A. N. Idiopathic scoliosis. Spine at onset of treatment. *B*, after wearing plaster of paris jacket constantly for one year. From Albee and Kushner: "The Albee Spine Fusion Operation in the Treatment of Scoliosis," *Surg., Gynec. & Obst.*, April, 1938, 66, 797-803. By courtesy of *Surgery, Gynecology and Obstetrics*.

removed, the spine collapses as Whitman aptly put it: "like an abandoned accordion." Obviously, to remove the brace, is to court disaster and both patient and physician will cling to it like the proverbial drowning man. *Furthermore, the utilization of the brace in a mild case will* often weaken the inactive muscles, increase the angle of deviation and set up a vicious cycle, converting a non-progressive spine to one requiring operative correction (Fig. 53). My position in regard to operation is this: *Corrective medical gymnastics without braces are carried on with* periodical check up by trunk x-rays, which I find the most trustworthy method of recording the lesion. As soon as it is realized that the spine shows a tendency to increasing deformity, in spite of conservative treatment, *operative stabilization of the spine is recommended. In the early*

A

B



C

Fig 54—*A*, same as Fig. 53 Correction of lumbodorsal curve with turnbuckle and hinged cast Turnbuckle not visualized. Compare with Fig. 53-B.

B, roentgenograms showing permanent fusion of lumbodorsal spine by means of bone graft, *A*, to prevent recurrence. Correction of dorsal curve by turnbuckle. Patient ready for second Albee fusion.

C, roentgenogram taken five months after second fusion operation. The lower pole of graft *B* was interlocked with upper pole of graft *A* at *C* so as to abolish articulation, construct an unyielding bony ridge, and as well to insure permanent correction. Note hypertrophy of graft *A*. From Albee and Kushner, "The Albee Spine Fusion Operation in the Treatment of Scoliosis," *Surg., Gynec. & Obst.*, April, 1938, 66, 797-803. By courtesy of *Surgery, Gynecology and Obstetrics*.

days before the employment of the bone graft, such cases were almost a "nightmare" to the surgeon as he was compelled to see the most pronounced deformities develop right under his eyes and his hands were completely tied as to prevention (Fig 56). The operative treatment has proved a great satisfaction.

Preoperative Treatment.—Maximum correction is obtained by the turnbuckle cast which may require several weeks to a few months. Operation is performed through a window cut through the plaster cast over

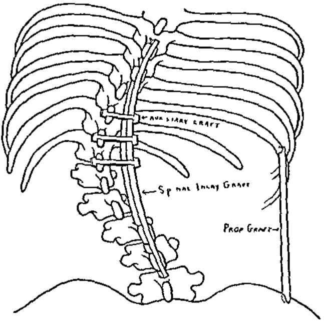


Fig 55—Schematic representation of prop graft (Fig 57) Note interlocking of graft and tenth rib, also auxiliary grafts at right angle to spinal graft, necessary in extreme degrees of curvature From Albee and Kushner, "The Albee Spine Fusion Operation in the Treatment of Scoliosis," *Surg, Gynec & Obst*, April, 1938, 64, 797-803 By courtesy of *Surgery, Gynecology and Obstetrics*

the area of primary curvature to be fused. The cast is retained for three months after operation and physiotherapy is then instituted If the area of spine involved be extensive, necessitating the inclusion of both curvatures within the field of operation, then a second cast is applied; correction of the second curvature is accomplished with a turnbuckle plaster cast and a second bone graft is inlaid into this curvature. Except in the most advanced ones, if the primary curve is fused in correction, the secondary one responds to this influence and correction follows. Control of the primary curve is usually sufficient; second operation is necessary in only about 10 per cent of cases.

Fig. 54 illustrates the various procedures The lower pole of graft *B*

was interlocked with the upper end of *A* at *C*, welding the unstable chain of articulations into a solid bar of bone. An increase in height of several inches is often noted as a result of "opening up" the curves with turnbuckle and hinged cast before operation. This method of re-alignment by an eccentric hinge and turnbuckle brings a powerful force to bear upon the curvature. *For description of technic see page 79.*

Prop Graft.—In the most extreme cases of paralytic scoliosis where

A B

Fig 56.—*A*, left Patient E P. Idiopathic scoliosis. Spine at onset of conservative therapy. *B*, corkscrew spine after prolonged treatment by corrective exercises, braces, plaster jackets and traction From Albee and Kushner, "The Albee Spine Fusion Operation in Treatment of Scoliosis," *Surg, Gynec. & Obst*, April, 1938, 66, 797-803. *By courtesy of Surgery, Gynecology and Obstetrics.*

the lower ribs telescope into the pelvis, I have now been doing for fifteen years, an operation (supplemental to the inlay graft) which has been giving excellent results.

In brief, it is a bone graft prop from the 10th rib to the crest of the ilium. This rib has been chosen because it is in itself a strong rib furnishing a stable anchorage of the thoracic cage to the graft (Fig. 55).

Technic.—An incision is made from the anterior end of the 10th rib to the crest of the ilium a little anterior to the axillary line, developing the anterior end of the 10th rib and the crest of the ilium. The lower border of the rib is shaped into a wedge to receive the wedged notch of the graft end. The crest of the ilium is shaped in a similar way.

With the partial correction already obtained from the action of the frame upon which the patient has been lying for weeks before the operation, or by turnbuckle cast plus strong lateral and upward digital pressure by assistants, the ribs are pulled upward from the ilium to the maximum, and this distance is measured by either a flexible probe or by calipers. The antero-internal surface of the tibia is then laid bare, and a strong graft of sufficient length (as determined by calipers or probe measurement) and ⅝ inch wide is obtained by the twin saw. Its ends are notched The graft is then put in place and the mortising effect of the notches in contact with the convex wedge surfaces already prepared upon the 10th rib and the ilium are sufficient to hold it firmly in place, as there is marked tendency toward the approximation of the ribs to the ilium This immobilization is still further added to by the careful suturing of the soft parts around the graft (See Figs 56, 60.)

Fig 57—Same as Fig 56 Four years after operation showing bone graft holding securely the corrected position of ribs after they were extracted from the pelvis at operation See Fig 55 Union with tenth rib at *A* Note increased density of tenth rib—also hypertrophy of spinal graft *Full correction not attained because* of extreme contracture of soft tissues on concave side following extended conservative therapy This *patient indulges in the most strenuous* exercises, including skating and tennis From Albee and Kushner "The Albee Spine Fusion Operation *in the Treatment of Scoliosis,*" *Surg Gynec & Obst*, April 1938, 66, 797 803 By courtesy of *Surgery, Gynecology and Obstetrics*

VERTEBRAL FRACTURES

Spine fusion may be employed to advantage in treating the traumatized vertebral column under certain well-defined conditions. It may conveniently be regarded as an operation of expediency, choice or necessity, depending upon the extent and sequelae of the initial trauma

Compression Fracture of Vertebral Body.—In simple compression fracture without cord involvement, where the anterior border of the body has been telescoped, producing the characteristic wedge, spine fusion may be considered as a move of expediency. By no means is it advocated as a routine procedure. Davis, in 1929, demonstrated that complete reduction of this type of fracture may be anticipated when the hyperextension method he described is employed to unfold the collapsed body. The integrity of the anterior longitudinal ligament permits trac-

tion to be exerted upon the crushed vertebra from above and below so that a mould of normal contour is formed around the fragments which in time will be filled with callus. This method has gained complete acceptance amongst bone surgeons and several variations of this technic have since been described, all based on the principle of reduction by hyperextension and fixation in a cast with early weight bearing. Böhler, Rogers, Dunlop and Watson-Jones, have all made worth while contributions in establishing the feasibility of reducing or unfolding compression fractures.

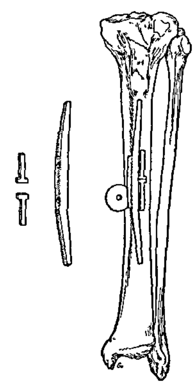


Fig 58—Method of cutting curved graft and two bone keys for fusion of the spine in severe scoliosis See Fig 59.

Immediate hyperextension is also indicated if by chance there happens to be a rupture of a nucleus pulposus in the traumatized area of the spine.

Immediate treatment consists of recumbency and hyperextension upon the Bradford frame (or Gatch bed). Traction may or may not be necessary in addition to hyperextension. In fractures of the cervical spine, it is almost always essential. This immediate treatment is followed by application of a plaster jacket, or spinal brace for four to six months; or the insertion of an inlay graft, to include the spinous process of the involved vertebra and one healthy vertebra on either side, by the same technic as for Pott's disease.

A word may be said here as to the use of the inlay graft as primary treatment for fresh fractures of the spine. Points in its favor are that it materially cuts down the period of convalescence (two months instead of six months or longer), and obviates the possibility of kyphosis. If the patient is treated conservatively, he may be well at the end of six months, or he may still have symptoms (with or without kyphosis) and require operation at that late date. It is, in most instances, a matter for the patient to decide whether he wishes to undergo operation with a greater certainty of cure and activity at the end of two or three months; or first try conservative treatment requiring inactivity for six months, with the possibility of an unsuccessful outcome and consequent necessity of operation in the end. Whenever there is non-

union, one finds a progressive destruction of bone similar to that observed in Kümmell's disease With the exception of athletes and those desiring to return to physical activity at the earliest possible moment, my practice is to treat such cases of fracture of the vertebral body conservatively If, after a fair trial of the conservative treatment, pains in the back persist and radiate along the intercostal nerves, with pronounced weakness of the back (in other words, symptoms identical to those of unhealed Pott's disease), I then recommend the implantation of a tibial graft The results obtained have been most gratifying

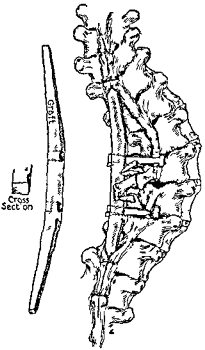


Fig 59—When extreme degrees of curvature are encountered and manual correction at the operating table is resisted by contracture of the soft tissues—the graft is inlaid as shown above The two vertebrae at the apex of the curve are immobilized by bone keys coapting the spinous processes and the longitudinal graft. Drill holes are made before removal from the tibia See Fig 58

ILLUSTRATIVE CASES

I A patient was seen in consultation some years ago, illustrating this point An active athletic male, twenty seven years old had been thrown from his horse while playing polo and a severe compression fracture of the body of the twelfth dorsal vertebra was found Two conflicting opinions arose one was to have the young man lie upon a gaspipe frame for four months followed by a plaster of paris cast for a period of three months, the other was to have a tibial bone graft inlaid into the spinous process of the fractured vertebra and the neighboring ones on each side The insistence of the patient that he wished to return at the earliest possible moment to polo and other strenuous athletic games was the deciding factor in recommending immediate operative fixation

II Patient was admitted with a history of having been injured in an automobile accident X ray studies revealed simple compression fractures of the body of the twelfth thoracic vertebra—a sequela of hyperflexion (Fig 62) Patient was anxious to insure an early return to arduous occupation involving the lifting of heavy weights It was felt that internal fixation of the spine would be followed by a minimum of disability and on this basis the patient elected the operation to be performed After reduction of the fracture by hyperextension a tibial bone graft was inlaid (Fig 61) (using the same technic employed in Pott's disease) See page 60 The jack knifing at the time of the accident had been so thorough that all ligamentous structures between the spinous processes of 11th and 12th dorsal vertebrae had been completely torn After making the skin incision the operator was surprised to encounter a large hematoma at the depth of which lay the

unprotected spinal cord. Weight bearing was permitted in 8 weeks without braceage and regular work in 16 weeks.[6]

Operation of Choice.—*As a treatment of choice,* there are several well-defined conditions resulting from spinal injury where brilliant results can be obtained by fusion.

1. *Kümmell's Disease.*—The work of Schmorl corroborated experimentally by Compere and Keyes has indicated that collapse of the vertebral body is due to the leakage of nucleus pulposus material through a

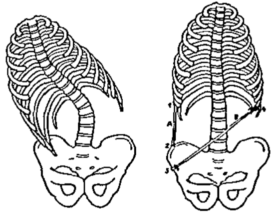


Fig. 60.—Vertical prop graft *A* at 1 and 2 augmented by strip of fascia lata *B* secured to the ilium at 3 and the tenth rib at 4 on the opposite side.

tear in the intervertebral disk and the formation of a nonossifying cartilage mass in the body of the affected vertebra.

The softening and collapse of the body gives rise to a deformity not unlike Pott's disease. After a more or less severe sprain or injury to the back, causing very little suffering, the patient soon returns to his work, and only after weeks or months does severe pain call his attention to a rounded kyphosis, generally in the dorsal region.

The prognosis is good, and the best results are obtained by fixing the spine either by plaster jacket, or, if the case is severe, by the author's operation as done for Pott's disease.

2. *Fracture of Articular Processes.*—Spinal fusion has proven effective in the treatment of isolated fractures of the articular processes. These lesions are difficult to demonstrate with an x-ray, necessitating repeated examination and careful focusing in the oblique position before a diagnosis can be made. Spies states that this fracture practically never unites. Prolonged disability results unless adequate measures are taken.

[6] Albee, "Trauma of the Spinal Column," *Surg., Gynec. & Obst. J.,* Vol. LVIII, p. 509-510, February, 1934

Mitchell reported five such cases in which "two patients did not respond to conservative treatment, and in these cases, a spinal fusion was performed. At operation the involved processes were exposed, the fractured tips and the cartilage of the facets removed, and a tibial graft placed between the split spinous processes. Immediate relief of symptoms was

Fig 61—Compression fracture of first lumbar vertebra

noted in both cases following operation, and one patient had no recurrence of symptoms ten months later."

Mensor found that 22 out of 141 patients with spinal injuries had such a lesion He remarks that surgery is often indicated (facetectomy and spinal fusion).

In this condition, it is unwise and unnecessary to attack the nonunion itself or articular cartilage of the joint. The inlay graft into the spinous processes is sufficient to prevent further motion by immobilizing the joint. By attempting to curette away the joint cartilages, the operating time is unnecessarily prolonged At any rate, with a nonunion of the

articular process, a fusion of its joint would be of no avail. It is not feasible to attack such a condition locally.

3. *Fracture of Two or More Vertebrae.*—Conservative treatment in fractures of two or more vertebrae with little or no nerve involvement

Fig 62.—Same as Fig 61. Reduction by hyperextension and immediate fusion of thoracolumbar spine by bone graft Operation performed to facilitate early return to arduous occupation

does not hold out the possibility for early functional restoration that fusion does. Usually there is a complete disorganization of the mechanical set-up, resulting in irritation of the nerve root and persistent pain. In such instances, complete relief has been secured by bone graft fusion many years after. It is wiser to arthrodese a severely traumatized area immediately in many cases than to wait for spontaneous fusion. The latter course is uncertain and a gamble on a favorable outcome.

4. *Disability Following Non-Reduced Compression Fracture.*—Davis reported 30 cases of old unreduced fractures with disabling symptoms, which had been inadequately treated by others. Fusion of the spine was

done in 13 of these cases Several of these patients had some residual disabling symptoms following fusion The majority, however, have returned to their former occupations without disability

Vertebral Fracture with Nerve Involvement—Authorities disagree as to the advisability of exploring the spinal canal when fracture of the vertebra is complicated by trauma to the nervous tissue In the event of complete loss of cord function, my position is that—as long as the neurologists and roentgenologists are unable to give trustworthy opinions as to whether the cord is completely or partially destroyed, or whether absence of function is due to irritation or pressure—one is justified in doing early laminectomies and thus give the patient the benefit of the doubt

Briefly, the following case illustrates this point Some 15 years ago, I saw at the Mary Fletcher Hospital, Burlington, Vermont, a young man with complete paralysis below the waist The history was that four days before while working as linesman for the local electric company, he had fallen about 9 feet from a pole after contacting a live wire X-rays in two planes gave no indication as to whether the interference with the transmission of nerve impulses was due to contusion of the cord or pressure from a displaced fragment of bone A neurologist and surgeon had recommended against surgical interference At laminectomy, I found a block of bone, detached from the lateral mass, in the neural canal Its removal resulted in ultimate complete recovery

It is not within the purview of this book to analyze the anatomical, physiological or pathological reasons pro or con surgical intervention However, if the surgeon feels justified in exploring the cord, then it is advisable in many instances, particularly in the cervical spine, to do a hemilaminectomy, leaving the spinous process intact for subsequent or immediate implantation of a tibial graft Postoperative dislocation of the cervical spine has been described following bilateral laminectomy with disastrous results in some cases Mixter and Osgood reported the sudden death of a patient during the act of sneezing while convalescing from a laminectomy for atlanto axial dislocation Taylor wrote "If there is any recovery from the neural trouble there will be nothing following bilateral laminectomy to hold the lumbar spine in place except the external ligaments, since the arches and intervertebral disks are gone, whereas if it had been possible to retain the spurs and laminae of one side, they would have given much strength in themselves and would have furnished good groundwork for fusion or an implant of bone "[7]

[7] A S Taylor *Ann Surg*, 1910 51 529 540

In this connection, Barr in writing on laminectomy for removal of ruptured nucleus pulposus states: "The question of whether a spinal fusion should be performed following the laminectomy is of great importance. On theoretical grounds, it would seem that a spinal fusion might help to prevent further posterior displacement of intervertebral disk tissue and recurrence of symptoms. If the laminectomy has been so extensive as *to remove one or more of the articular facets*, it would seem advisable to perform a spinal fusion to insure sufficient stability for the spine. This might be done either at the time of the laminectomy or at a *second* operation. In twelve of the forty cases in this series, a spinal fusion was done at the same time as the laminectomy." [8]

Kellogg Speed adds: "Bone transplantation to stiffen the spine and afford support after laminectomy or after old fractures with increasing deformity unreduced and accompanied by pain is also an operative step of value. This is done in accordance with Albee's and Hibbs' method [9] *after the wound of laminectomy has healed and there is assurance of no* pressure on the cord with as much return of function as can be expected. This avoids the prolonged wearing of a brace or plaster jacket and if there are no residual paralyses, makes the patient nearly as independent as before the fracture." [10]

TECHNIC OF COMBINED HEMILAMINECTOMY AND BONE GRAFT

Alfred S. Taylor, of New York, *claims originality and priority in the* performance of unilateral laminectomy, which he first performed in 1908, and which consists of the removal of portions of the laminae of one or more vertebrae on one side of the spinous processes only. The use of the author's electrically driven laminatome (Fig. 63) and his other motor-driven instruments have greatly simplified the performance of this operation.

The site of the proposed laminectomy is exposed by a long curved incision. By retracting outward and by blunt dissection and the use of the periosteal elevator, the muscles are separated from the lateral aspects of the spinous processes and the dorsal surfaces of the laminae. Hemorrhage, if troublesome, is best controlled by hot saline compresses.

[8] J. B. Barr, *J. Bone & Joint Surg*, April, 1937, 19:2, 323-342.

[9] The extensive removal of bone at a strategic point in a hemilaminectomy burns the bridges completely (so to speak), so that a Hibbs' *operation cannot* be done. It does not interfere with the Albee procedure.

[10] Kellogg Speed, *A Textbook of Fractures and Dislocations*, 3rd ed., Lea and Febiger, Philadelphia, 1935

The neural arch is then pierced by means of a spinal rongeur by a hole of sufficient size to admit the author's electrically driven laminatome, with which a path is cut through the desired number of laminae above and below the original hole By this method, the author finds that the

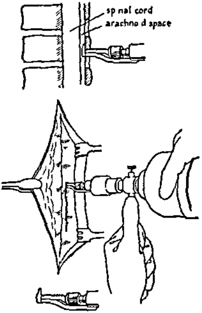


Fig 63 —New oscillating electrical laminatome attachment to Albee bone mill guard is introduced into arachnoid space and a path is cut through the desired number of laminae above and below this point See Fig 18

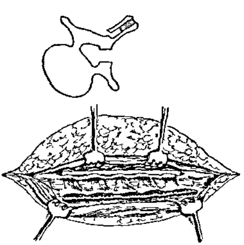


Fig 64 —*Right hemilaminectomy of five* vertebrae with a tibial bone graft inserted into the corresponding spinous processes The spinous processes are split and the halves broken on opposite side (left) and graft inserted as for Pott s disease at the time of the hemilaminectomy or later if found necessary *to support or immobilize the spine From* Albee *Orthopedic and Reconstruction Surgery* W B Saunders Co

spinal canal can be quickly and safely entered within a very short time and with a minimum amount of hemorrhage

The spinous processes are then split on the side opposite the exposure and the graft inserted as for Pott s disease at the time of the operation or at a later date if the condition of the patient precludes additional surgery (Fig 64)

FUSION FOR FRACTURE-DISLOCATION OF CERVICAL SPINE

(Frequently an operation of necessity)

Whereas there has been a trend toward conservatism in the treatment of simple fractures of the lumbosacral spine, the treatment of injuries to the cervical spine has inclined more and more toward operative inter-

vention. Progress in traumatic spinal surgery has been most outstanding in this region. Recent developments in methods of reduction, re-alignment by skeletal traction, and recognition of the necessity for operative fixation of the cervical spine have brought about more satisfactory results than has been possible heretofore. Different technics for skeletal traction have been described by Hoen, Cone and Turner, Crutchfield, and McKenzie. Crutchfield has developed a very practical ice-tong caliper which is hooked into drill holes in the skull and up to 25 pounds traction applied. He believes it to be the method of choice because of the high percentage of reduction obtainable, the controllable force and comparative comfort afforded.

Fig. 65—Method described by Cone and Turner for fusion of the cervical spine Old fracture-dislocation of the fourth cervical vertebra on the fifth. This shows the eventual reduction obtained on the operating table and the bone grafts. From Cone and Turner, "The Treatment of Fracture-dislocations of the Cervical Vertebrae by Skeletal Tractions and Fusion," *J Bone & Joint Surg*, July, 1937, 19, 3:584.

Cone and Turner demonstrated complete traction in 15 minutes by using 25 pounds traction on a patient with a dislocation of C5 and C6. Roentgenograms were taken every ten minutes.

After reduction the question arises as to how recurrence of the deformity can best be prevented. From the increasing number of reports published of redislocations following removal of cast or brace, it is apparent that some form of operative stabilization is indicated.

Many of the cases described developed cord involvement several months to twenty years following the initial injury, which had only affected the bony structure at the time. In one patient, paraplegia recurred from repeated dislocations on four different occasions.

This problem has engaged the attention of many surgeons, and the majority agree that in *spine fusion* lies the answer. Cone and Turner

employ parallel tibial or rib grafts secured with silver wire sutures (Fig 65) Gallie comments "The necessity for an open operation in these cases of forward dislocation of the cervical spine is less to be regretted when one remembers the marked tendency they have to recur, even after prolonged immobilization Our experience has convinced us that one can foretell from the roentgenograms which cases are likely to have a *tendency to recurrence after removal of the plaster encasement and to save time by doing the fusion operation at once*"[11]

Technic of Fusion of the Cervical Spine—The technic of the operation is similar to that described for Pott's disease (see page 59) The author makes use of a solid tibial graft shaped as in Fig 66 and secured to the occipital bone with kangaroo tendon introduced through drill holes

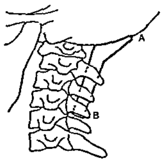


Fig 66—Author's method of shaping tibial bone graft for cervico occipital fusion to prevent dislocation of the atlas

CONGENITAL DEFORMITIES

Spina Bifida.—In cases of spina bifida, where the meningocele has been controlled, and a large deficiency of vertebral bone exists together with weakness as evidenced by lordosis *or other deformity, the bone graft offers an excellent means for strengthening the spine weakened from the congenital bone deficiency This same treatment* may be indicated for symptoms of pain, weakness, etc, even when no deformity has resulted

Author's Technic—The technic is somewhat similar to that adopted in Pott's disease Modification is necessary on account of the absence of spinous processes and parts of neural arches The spinous processes above the cleft and the lateral masses of the last lumbar vertebrae and the first part of the sacrum are reached from each side by two curved *skin incisions, as it is undesirable to interfere by a midline approach with* the nerve tissue which is usually involved in the cicatrix following the operative reduction of the meningocele The second spinous process above the cleft is split longitudinally, and a greenstick fracture produced in each half The first spinous process above the cleft is denuded of its muscular and ligamentous attachments and both sides are freshened so that the grafts which are inlaid into the next spinous process above will contact it on either side Below the cleft, the lateral masses of the fifth lumbar vertebra (or the congenitally deformed stumps of the neural

11 W E. Gallie *Ann Surg* Oct., 1937 106 770.

arches if sufficiently prominent) and the first segment of the sacrum which is usually congenitally hypertrophied, are split with the osteotome, and the halves are separated to receive the lower ends of the two grafts. The spina bifida cleft is usually wide enough below that the grafts assume the position of an inverted V.

The wounds are packed with saline compresses, and the two grafts are removed and prepared from the crest of the tibia, being long enough to reach from the split spines above to the sacrum below. The upper ends are beveled, so that when these beveled surfaces come together, the grafts form an acute angle, like an inverted V. The grafts are placed at this angle in the beds prepared for them, and are held firmly in place in their bony contacts by drawing the split ligaments over them with interrupted sutures of medium kangaroo tendon (see Fig. 67). Skin wounds are closed and the patient placed on a fracture bed for 8 weeks.

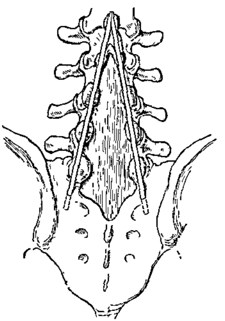


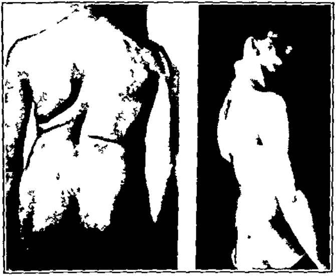
Fig 67—Drawing illustrating author's technic of inserting a tibial graft to straighten and support a lordotic bifid spine (spina bifida) From Albee, *Reconstruction Surgery*, W. B. Saunders Co

Hemivertebra.—Codavilla first suggested excision of the hemivertebra in a case of congenital scoliosis, but then rejected the idea as theoretically sound but in practice too dangerous. In 1928, Royale, of Australia, successfully removed part of a congenitally wedged vertebra in a child 2½ years old. In 1932, Compere reported a successful complete excision of a hemivertebra and in 1933, von Lackum and Smith removed the vertebral body for a case of scoliosis (Bick).

The operations described were extensive ones, necessitating careful dissection among vital structures, such as the spinal cord, spinal nerves, pleural cavity, etc. (The latter structure was accidentally opened in one case.) Operative shock is, of necessity, difficult to control, and makes the operation a hazardous one. The successful employment of the bone graft, implanted into the spinous processes for the treatment of idiopathic and paralytic scoliosis has pointed the way to a practical solution of the therapeutic problem in these cases. So long as motion between the vertebra can be abolished by a successful fusion operation, the congenital

anomalies become of no consequence provided the curvature can be reasonably corrected This is easily accomplished in a child's spine under anesthesia because *the soft structures on the concave side yield and have* not had time to contract The graft is inlaid, using the same method described for paralytic scoliosis (page 78)

Mayer has demonstrated that the presence of a hemivertebra does not interfere with manual correction of the deformity, which is then treated conservatively However, I believe the conservative treatment, which necessitates years of braceage, to be unduly prolonged and neither trustworthy nor justifiable in view of the results obtained with the bone graft Permanency is assured and a return to normal childhood accelerated



A B

Fig 68—*A* case of spondylolisthesis in a young man of 18 following an injury in a prize fight Deformity reduced and reduction maintained with bone graft

B illustrating a case of the application of the bone graft for marked spondylolisthesis of the lumbar vertebra on the sacrum A strong graft removed from the tibia has fixed this segment of the spine to the sacrum correcting the lordosis and relieving all symptoms From Albee, *Orthopedic and Reconstruction Surgery* W B Saunders Co

SPONDYLOLISTHESIS

Spondylolisthesis is the term derived from the Greek, meaning gliding of the vertebra, applied to a forward subluxation of the body of the fourth or fifth lumbar vertebra, together with a superimposed vertebral column, on the vertebra below it, or on the sacrum (Mercer) (Fig 68)

The rationale of treatment is almost entirely mechanical, in that the symptoms are due to vertebral displacement, resulting in over stretching

and undue tension upon the ligaments surrounding the vertebrae, which is increased by *standing and lifting.*

Up to the introduction of the immobilizing spine operation, no satisfactory treatment had been devised for this most unfortunate condition, since it was not *controllable by splint methods. It is apparent that little* can be accomplished by the application of braceage or plaster jackets, in that the only counterpressure that could possibly be effectual must come anteriorly, in order to exert its influence on the *anterior surface of the* vertebral bodies displaced. Obviously, pressure through the abdominal cavity cannot be sufficiently immobilizing to be of any value and this accounts for the fact that no cure by braceage treatment is reported in the literature. Rest in bed, by diminishing the pull on the ligamentous structures, affords temporary relief only.

The mechanical features of the bone graft as applied by the author to immobilize the spine are exceptionally well adapted to this most difficult problem, in that a strong graft inlaid into the spinous processes of the lower lumbar vertebrae and carefully coapted onto the posterior surface of the sacrum affords a very firm immobilization, particularly as the large and strong spinous processes of the third, fourth, and fifth lumbar vertebrae provide unusually firm anchorage for the graft, as the stress upon the graft comes in an anterior direction. As the tendency is for the *old deformity to relapse, and for the lumbar vertebrae to sag forward,* this only forces the lower end of the graft more firmly against the posterior surface of the sacrum, when the graft has grown into the spinous processes of the vertebrae. Fortunately, therefore, there is not the necessity of as firm an inlay anchorage into the sacrum as there is in the case of the vertebrae.

The graft should always be anchored into the spinous processes of at least two vertebrae above the displacement: if the displacement is at the lumbosacral junction, the graft should be inserted *into the fourth* and fifth lumbar vertebrae, whereas if the displacement is between the fourth and fifth lumbar vertebrae, it should be inserted into the spinous processes *of the third and fourth lumbar vertebrae,* which lie above the displacement, and the fifth vertebra and sacrum which lie below it.

Acknowledgment should be made to Ryerson, who, in 1915, reported successful treatment of a severe case of traumatic spondylolisthesis by "immobilizing the lower lumbar spine by the Albee bone splint method." So far as I know, he was the first to report this use of *the inlay* graft. His technic was very similar to that described here, except that braided silk sutures were used instead of kangaroo tendon.

Technic.—The spinous processes of the lower lumbar vertebrae and

posterior part of the sacrum are laid bare by an incision curving slightly to the right side Exposure is afforded by turning up a flap consisting of skin and soft parts down to the superficial fascia

The supraspinous and intraspinous ligaments are split by the scalpel, passing over the central portion of the tip of the spinous processes and in between them The small spinous processes on the posterior surface of the sacrum are likewise located and the ligamentous structure split over their tips and in between With a sharp broad Albee osteotome, the spinous processes of the lumbar vertebrae are split longitudinally as near their centers as possible care being taken not to fracture the halves of

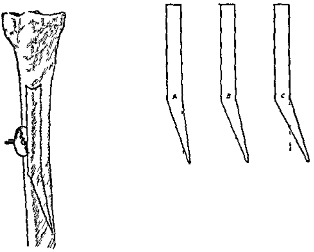
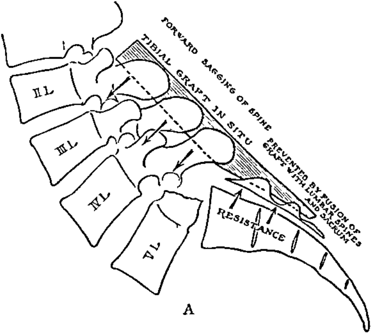


Fig 69—Diagram showing contour of graft as it is being removed with motor saw from the antero internal surface and crest of the tibia

A B and *C* variations in the lower or sacral portion of the graft in accordance with the obliquity found between the posterior surface of the sacrum and general alignment of the lumbar spine From Albee Spondylolisthesis *J Bone & Joint Surg* Jan 1927 9 3-443

the spinous processes opposite the operator (the operator standing on the left side of the patient) The portion of the spinous process toward the operator is forced laterally toward him and may be in more than one fragment, but as these fragments are imbedded in the firm intraspinous ligament, no disadvantage is entailed The small spinous processes of the upper two segments of the sacrum are treated likewise, and their left halves displaced with the imbedding ligaments sufficiently lateral to allow a graft of the full thickness of the tibial cortex to be inserted between them

After the spinous processes have been split, shavings and particles of bone are turned toward each other and the sacrum from the inferior surface of the next spinous process above it This is done to add addi-



A

B

Fig 70—*A*, tracing of x-ray 8 months after operation. This tracing shows the conformation of the graft, and its position in the spinous processes of the lumbar vertebrae and insertion into the posterior surface of the sacrum. The arrows indicate the direction of forces which are exerted upon the graft as a result of its immobilizing influence.

B, fusion of spine in a case of spondylolisthesis showing tibial bone graft, *BG*, immobilizing lumbosacral spine. From Albee, "Spondylolisthesis," *J. Bone & Joint Surg*, Jan., 1927, 9, 3

tional osteogenetic material and influence to the graft to be inserted later With an osteotome and curette the posterior area of the sacrum with which the graft is to be coapted is thoroughly scarified

By means of a lead bar or a flexible probe, the entire contour of the proposed graft is obtained The contour of the graft is illustrated in Figure 69 Extreme care should be taken to get an accurate pattern of the posterior part of the sacrum and its angulation with the general axis of the lumbar column

The spinal wound is then packed with a hot saline compress, and the antero internal surface of the central portion of the left tibia is laid bare by an incision from the crest

With the moulded probe as a pattern, the proposed graft is carefully mapped out on the anteromesial surface of the tibia by means of strokes of the scalpel in the periosteum As it is desirable to have the sacral end of the graft stronger, this will be the inferior end, because the cortex in the lower end of the tibia is thicker than in the upper

As soon as the graft is removed, it is inserted into the bed already prepared for it in the lumbar vertebrae and sacrum It is firmly seated, particularly onto the sacrum, by means of the bone set (the counterpart of the carpenter s nail set) and mallet, force being exerted to overcome as much as possible of the spondylolisthetic displacement The deformity is further corrected by the tension of the strong kangaroo tendon sutures which are used to grasp and immobilize the graft thoroughly in the firm ligamentous structures of the lumbar spine and sacrum (Fig 70)

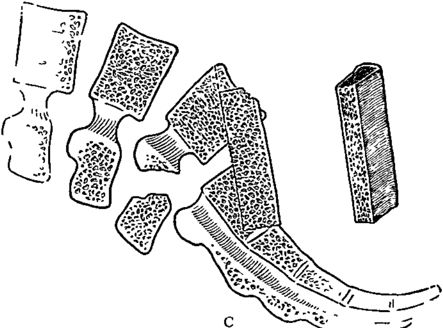
The back and leg wounds are closed in the same manner Generous dressings of gauze and absorbent cotton are applied These dressings should be particularly large over the spinal wound

The patient is then placed in the dorsal position upon a fracture mat tress, where he is kept for seven weeks A low corset brace is then applied, with a surcingle around the lower end This is worn for from four to six months

Mercer's Technic—The patient is placed on his back and the table raised at its lower end to produce an exaggerated Trendelenburg position A long midline incision is made to just above the umbilicus The abdominal contents are packed off from the area of operation and a self retaining retractor inserted The subluxated vertebra is now inspected and its relat on to the iliac vessels ascertained The gap between the sacrum and the slipping vertebral body is now exposed by dividing the posterior peritoneum over it ligating some small veins and the middle sacral artery and freed of overlying fatty fibrous tissue with a gauze swab An osteotome is now used and driven in an antero-posterior direction into the lower margin of the fifth lumbar vertebra an e ghth of an inch from its lower edge and into the upper margin of the sacrum an eighth of an

A

B



C

Fig 71 —*A*, Mercer's technic for spondylolisthesis Exposure of operation area and emplacement for graft.

B, grafts being placed in position.

C, area suggested for graft. From Mercer, "Spondylolisthesis," *Am. J. Surg*, Feb., 1939, Vol. 43.

inch from its upper edge In this way, a rectangular hole is produced after the pieces of bone and the intervertebral disc have been removed Autogenous bone grafts are now taken from the crest of the ilium to wedge into this gap Two pieces are taken since a single piece cannot be gotten broad enough to wedge in firmly The grafts are now hammered tightly into the gap between the sacrum and the fifth lumbar vertebra and further screwed into place to insure their retention If they are not screwed in it has been found that when the patient is lifted off the table the lumbosacral gap may be opened up and the wedges of bone spring out To avoid this in addition to screwing the grafts in the operation is usually carried out with the patient in a posterior plaster shell The patient remains in the shell for four months and then lies free from restraint in bed for another month Thereafter he is allowed up in a Goldthwaite brace (Fig 71)[12]

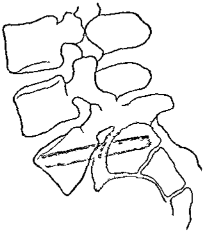


Fig 72 —Speed's method of inserting tibial bone graft anteriorly for spondylolisthesis The transplanted bone penetrates through the corpus of the fifth lumbar vetebra past the lumbosacral intervertebral space on into the sacrum and nearly to the sacral canal This transplant is sizable and should lead to bony fusion No part of the transplant projects beyond the anterior margin of the body of the fifth lumbar vertebra From Kellogg Speed Spondylolisthesis *Arch Surg* August 1938 37 2

Speed's Technic (Fig 72) —An attempt may be made by suspension traction in bed to overcome some of the displacement of the fifth lumbar vertebra, depending on the duration of the condition and the roentgenologic findings

An abdominal incision, midline umbilicus to pubis, permits full exposure of the sacral promontory after the patient is tilted back and the intestines are packed away The promontory is palpated, and the exact condition and extent of rotation of the fifth lumbar vertebra are determined in order to confirm the roentgenologic findings If the bifurcation of the aorta is low, it may, along with the left common iliac vein, be gently held back by a padded retractor The peritoneum over the fourth interspace down to the sacrum is incised just to the right of the midline, and an effort is made to avoid the midsacral nerve and artery and the ganglia of sympathetic nerves If the artery bleeds, it must be tied The amount of displacement and angulation having been decided, a chisel is used to make an entrance into the vertebral bony mass at or below the level of the fourth interspace The angle required to penetrate the body of the fifth lumbar vertebra and to enter the sacrum must then be decided, and a large drill is inserted through the body of the fifth lumbar verte-

[12] Walter Mercer, *Edinb M J* 1936 43 545

bra obliquely, nearly directly downward, as the patient lies supine. Its point can be felt passing through the lower or posterior border of the body of the fifth lumbar vertebra, to enter the intervertebral space and then pass on into the new resistance of the sacrum. The depth of the hole made by the drill and the length of graft required may be predetermined by measurement. A bony transplant from the tibia or any other source, of the same diameter as the hole, is then tapped gently into place; the subperitoneal tissue is approximated with interrupted catgut and the posterior peritoneum with a running stitch of catgut, and the abdomen is closed completely without drainage.

No plaster bed or splint seems necessary in after-treatment. A moderately firm mattress or fracture bed, which permits nursing care without flexion of the back, is used. Confinement in bed lasts eight weeks and is followed by ambulation and the use of a steel back brace until there is roentgenologic evidence of bony fusion.

The technic of anterior fusion of the fifth lumbar to the sacrum has been described in recent years by Jenkins, Burns, Mercer, and Speed. Although this method is of interest from a technical standpoint, yet it fails to meet the mechanical requirements existing in spondylolisthesis. A study of Figure 72 indicates that the graft which must be directed almost horizontally through the body of the fifth lumbar vertebra in severe spondylolisthesis will be subjected to a shearing stress exerted by the weight of the superincumbent vertebrae and upper part of the body. Furthermore, the approach through the abdominal cavity increases the risk of postoperative complications. The bone graft implanted posteriorly into the spinous processes is exposed to a more favorable stress in so far as the gravital force of the spine tends to increase the coaptation of the bone graft with the lumbar spine and sacrum, and thus constitutes a bone block to further dislocation.

Kleinberg advises fusion of the vertebra as a prophylactic measure in so-called pre-spondylolisthesis to prevent future dislocation (Figs. 73, 74).

Mathieu and Demirleau describe a method for iliolumbarosteosynthesis for spondylolisthesis. In principle, it consists in the introduction of a very rigid and powerful graft through a hole in the iliac wing transversely into the split transverse processes of the lumbar vertebra. Two separate grafts on each side; the one uniting the iliac crest with the transverse process of the fifth lumbar and the other between ilium and the fourth lumbar transverse process. In addition, this iliolumbar arthrodesis should be combined with the lumbosacral arthrodesis, so that the

osteosynthesis makes a ligamentous distention impossible The technic is as follows

First incision T' shaped composed of two parts a concave shank horizontally downward beginning at the level of the postero superior spine and running along the

Fig 73—Lumbosacral *fusion by posterior bone graft (author's method) in a case of low* back pain due to congenital non union of laminae and spinous process—so-called pre spondylolisthesis

posterior portion of the iliac crest 14 15 cms To this is added a perpendicular shank from the middle of the former incision obliquely upward and inward toward the fourth lumbar spinous process. The gluteal muscles are now detached with the knife along the crest of the os ilei and the crest is likewise freed from the muscular insertions at its posterior border

Then the transverse process of the fifth lumbar is exposed by freeing the sacrolumbar masses from the iliac insertion and then cutting them transversely to retract them inward Then with the chisel the upper portion of the posterior sacral ring is denuded and immediately above it one finds the transverse process of the fifth lumbar vertebra. This is normally at the plane anterior to the sacral ring, and in cases of spondylolisthesis this forward displacement is particularly pronounced

Perforation of the iliac wing, the gluteal muscles are retracted downward, the external surface of the wing is exposed, and an opening is made of a diameter just large enough to receive the rigid tibial graft which has been formerly removed by the electric saw.

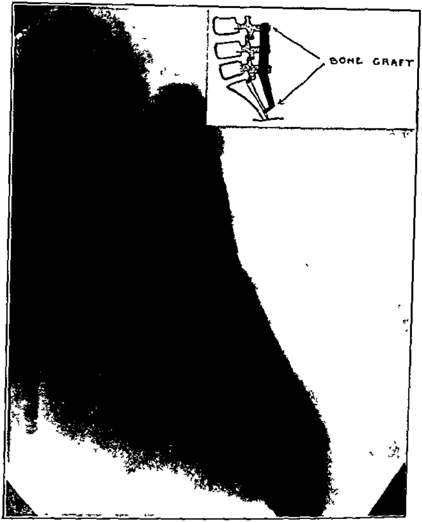


Fig 74.—Lateral view of lumbosacral spine following bone graft fusion Note angulation of graft to conform with sacral contours at its midpoint and kink at lower end to insure firm anchorage into sacrum.

With a fine chisel the transverse process is then split in the frontal plane and the graft is introduced to the opening in the os ilei in such a way that its end becomes dovetailed between the two halves of the transverse process. Then the muscular aponeurotic tissue is repaired; the sacrolumbar ridges which had been split are sutured together.[13]

This operation is unnecessarily complicated and technically difficult. It does not meet the mechanical demands of the condition in a direct way.

[13] Mathieu and Demirleau, *Rev. d'Orthop.*, July, 1936, 10, Sect. A.

CHRONIC OSTEOMYELITIS OF THE VERTEBRA

Vertebral osteomyelitis manifests itself occasionally in a subacute or chronic form presenting a clinical picture that is almost indistinguishable from that of Pott s disease The recognition of the condition offers no particular difficulty in the fulminating type nor in those with posterior arch involvement often with abscesses It is the type with a lesion in one or more bodies with only a slight or moderate elevation of tempera ture and with pain that may be described as a little more than a backache which may be overlooked entirely or diagnosed as tuberculosis These infections commonly follow others in different parts of the body for which the patient has been confined to bed and when backache is com plained of is thought to be for some unimportant cause and no more attention is paid to it (Smith)

Diagnosis —Many of the cases described in the literature on this sub ject were mistaken for tuberculosis and treated by spine fusion on this basis However careful analys s of the clinical data will usually enable one to arrive at a correct diagnosis

1 *History* Backache following a history of staphylococcus infection elsewhere should leave one to suspect pyogenic infection if x ray appear ances indicate pathology Preceding history of tuberculosis elsewhere may be a determining factor in pointing to Pott s disease

2 *Pain* Although the intensity of pain will vary with different pa tients yet osteomyelitis tends to be more constant than in Pott s disease and unrelieved by recumbency

3 *Deformity* Kyphosis may be present but never as pronounced as tuberculosis

4 *X ray Appearance* Tendency to marked proliferation of bone is present in osteomyelitis followed by fusion of vertebrae In any case of spondylitis which has been studied by serial roentgenograms over a long period of time the presence of a localized uniform narrowing of the *intervertebral spaces with hypertrophic changes about the margins of the* vertebrae with or without abscess formation should suggest the possi bility of pyogenic spondylitis and the history should be investigated and further examination made from that point of view (Kulowski)

5 *Abscesses* Among the abscesses developing from chronic osteo myelitis of the lumbar spine the psoas abscess is in the foreground In other cases the abscess developing in the lumbar region extends along the crest of the os ilei Such abscesses may be the first suggestion that the lesion is not tuberculous A microscopic and bacteriologic examination

including guinea-pig inoculation is usually necessary in the chronic form of osteomyelitis of the spine to establish the diagnosis.

6. Positive blood culture rules out tuberculosis. Sedimentation time is of no value from a diagnostic standpoint (Pusitz).

Treatment.—In the benign type of lesion where spontaneous fusion of

Fig. 75.—Bone graft fusion of spine at *AB* for vertebral osteomyelitis Firm fixation obtained by bone graft augments reparative process. Arrow denotes abscess.

the vertebrae is likely to be unduly prolonged, the implantation of a tibial graft will materially curtail the duration of convalescence and benefit the patient by reducing the incidence of chronic disabling backache (Fig. 75). B. Koven reports a series of such patients treated by spine fusion operation with good results. A large percentage of cases will respond to conservative braceage treatment. If blood stream infection occurs, a specific laboratory-bred bacteriophage, prepared with the vegetable vehicle asparagin, should be administered intravenously.

Typhoid Spine
(Steindler)

Typhoid spondylitis is characterized by the relative benignity of infection which tends to take a subacute course by the period of latency between the onset of the disease and *the appearance of the spine symptoms and finally by the relative absence of suppuration* The most characteristic symptom is the violent pain in the back appearing during convalescence and involving principally the lumbar spine The pain radiates into the groin the abdomen the lower limbs and often follows the lumbar plexus and obturator distribution Pressure pain is very distinct over the spines of the lumbar section and over the long muscles of the back Contracture of these muscles produces attitudes of lordosis or scoliosis True gibbus formation is the exception it occurs only in severer cases Freiberg observed gibbus following pain and rigidity As a rule however weeks or months elapse before a change in the configuration is noticed Whether such deformation *is due to actual destruction in the anterior portions of the bodies with subsequent collapse* as Wullstein believes or is merely the effect of the destruction of the intervertebral discs is uncertain Neither the disappearance of the disc nor the bone bridges however, are strictly pathognomonic the same changes can be found in hypertrophic arthritis and *occasionally in tuberculosis Suggestive is the localization in the lumbar spine* and the fact that the disc disappears much more rapidly than is usually the case in arthritis or in tuberculosis and that there are no similar changes in other sections of the spine [14]

Treatment —*Conservatism has been the byword in treating this com*plication of typhoid fever Although a number of authors have described methods of draining the abscess, the acute state requires rest in bed with general supportive measures If the abscess has been incised a specific bacteriophage should be cultured and introduced locally and intravenously

We have employed this agent in treating typhoid bone abscess of the spinal and long bones After operation the wound is packed with gauze,[15] saturated with a compound consisting of paraffin 90 per cent and yellow vaselin 10 per cent at 120 degrees Fahrenheit A laboratory bred *specific type of bacteriophage is then employed locally and intravenously* In one case, a complete check of the bile, urine, stool and blood was made for B *typhosus* two months following the initiation of this treatment and all proved negative, although the stool and blood were previously reported as containing the bacillus

This method offers an excellent means of attacking a typhoid spondylitis although a stock phage may have to be employed intravenously if surgical drainage has not been instituted In the chronic stage, where the

[14] A Steindler *Diseases and Deformities of the Spine and Thorax* C. V Mosby Co., St Louis, 1929

[15] This is a modification of the Orr treatment where the packing consists of vaselin gauze only

patient's general condition appears satisfactory and progress of spontaneous fusion between the vertebra retarded, spinal fusion by tibial inlay graft will abbreviate the convalescence considerably and prevent long continued backache.

OSTEOARTHRITIS

Operative fusion of the arthritic spine is not the routine treatment, and is applicable only to very exceptional cases where the condition is markedly localized with severe symptoms. In some cases, the ultimate ankylosis of the spine develops very slowly and the patients are considerably tormented by neuralgias of all kinds, intercostal or sacrolumbar. In those instances, operative fusion will hasten the ankylosis and may be undertaken as a symptomatic measure. Either the bone inlay graft of Albee, or the spinal fusion method of Hibbs may be applied to good advantage (Steindler).

CHARCOT SPINE

The treatment of syphilitic spondylitis should be mechanical and medicinal. Rest, spinal support in the acute stages, and supplementary treatment will occasionally benefit the patient. It is essential that the treatment be prolonged for a year or more.

In many cases, because of adverse mechanical conditions, the symptoms persist and the bone graft, as applied by the author in Pott's disease, may be used in conjunction with antisyphilitic treatment as an immobilizing and supporting agent. An illustrative case is that of a young woman with a marked kyphosis in the dorsal region, with severe symptoms associated with lesions at the jaw and sternoclavicular joints. The spinal symptoms were immediately and entirely relieved by a bone graft, while at the same time the lesions in the jaw and sternoclavicular regions resisted for a long time the most strenuous antisyphilitic treatment.

VERTEBRAL OSTEOCHONDRITIS AND EPIPHYSITIS (ADOLESCENT KYPHOSIS)

Osteochondritis.—Calvé in 1921 described these conditions as a "localized affection of the spine suggesting osteochondritis of the vertebral bodies with the clinical aspects of Pott's disease. Vertebral osteochondritis sets in during the first few years of life and is characterized by

moderate or very slight pain, fatigue, night cries, muscle spasm, tenderness, deformity in the form of a knuckle or a generalized kyphosis or scoliosis (Buchman)

Roentgenographically, it is characterized by an irregularity of the vertebral outlines, flattening, and wedging of the vertebra to be followed by the stage of restitution when the vertebral outlines appear dense and sclerosed Deformity of the vertebral bodies is the final result The intervertebral spaces are widened in proportion to the thinning of the vertebral bodies

It is obvious that this condition may closely simulate Pott's disease and must be kept in mind when investigating the etiology of a kyphotic spine Many of the cases described in the literature were first diagnosed as Pott s disease and treated as such It was only when the subsequent course of the disease was observed that some suspicions arose that the etiology was not specific

In cases with progressive or marked deformities, prolonged treatment may be avoided by internal splinting of the spine with a tibial bone graft The kyphosis may be satisfactorily corrected by hyperextension on the operating table and the bone graft inlay inserted while in this position In severe deformities preoperative correction by turnbuckle plasters may be required Adequate internal mobilization may be obtained by including only one vertebra above and below the lesion since the tendency to collapse is not as manifest as in Pott s disease No cast is required and weight bearing is permitted in seven weeks The increased blood supply introduced from above and below through the bone graft to the cancellous systems of the involved vertebrae, aids in restoring the normal nutrition of the bone and secondly, internal splintage prevents recurrence of the deformity

Although the etiology of this condition still remains obscure, it cannot be denied that an increased blood supply must exert a reparative influence That this premise is true has been demonstrated by the good results obtained in drilling through the neck of the femur for Perthes' disease wherein a new blood supply is directed toward the capital epiphysis

Considering that braces have been used for periods extending to two or three years, it is a great advantage to restore the child to full activity in a short period by resorting to spinal fusion and eliminate the mental anguish and feeling of inferiority occasioned by the long use of braces

Vertebral Epiphysitis —Buchman described this condition as a self-limited affection involving the epiphyses of the spine, most commonly in the dorsal region Other epiphyses, such as those of the iliac crests or other parts of the body, may be involved concomitantly The condition

occurs between ten and twenty-one years of age. The onset is usually associated with a sensation of fatigue and backache and pains in the limbs. There is tenderness over the spinous processes, especially in the dorsal region. The lumbar vertebral bodies are occasionally tender on abdominal palpation. Deformity develops secondarily and it may be a kyphosis or a scoliosis. Frequently, the condition is entirely asymptomatic or the symptoms may be so slight that they attract little or no attention. The deformity is the disturbing factor and it is because of the deformity that the doctor's aid is sought. The patients are usually well-developed and well-nourished children.

These two affections—osteochondritis and epiphysitis—are undoubtedly parallel conditions going on in different periods of growth. Burns and Ellis, commenting on this question, observe three abnormalities of the vertebral bodies which may be noticed in cases of adolescent kyphosis.

1. The notch at the upper and lower anterior angles of the bodies of the vertebrae may be increased in size, and the epiphyseal centers may vary from the normal in size and density. These are Scheuermann's notches.

2. Failure of endochondral growth in the cartilaginous interspace and wedging of the body of the vertebra.

3. The appearance of cup-shaped areas of sclerosis occurring in the body of the vertebra around the intruding nuclear prolapse, usually situated somewhat behind the midline of the vertebra when seen in a lateral x-ray.

The first may be considered to be an epiphysitis, the second, an osteochondritis, and the third, a sequel of the second.

Tumors of the Vertebra.—The author has had occasion to treat patients dying from malignant vertebral tumor. Pain was so intense and uncontrollable in these cases that it was felt justifiable to undertake a major surgical procedure to alleviate their suffering. A tibial bone graft inlay immobilized the involved vertebra in these patients and afforded a remarkable measure of relief. In this instance, this operative procedure is applied for relief of otherwise uncontrollable pain and is rarely justifiable.

SACRO-ILIAC JOINT

It has become the vogue to suspect the sacro-iliac articulations as possible seats of the trouble in most cases of low back pain. The menace of this practice is a tendency to resort to serious surgical interference in lesions which can often be relieved by sound conservative treatment.

Relaxation of the Sacro Iliac Joint —Within the last ten years, I have become increasingly convinced that simple relaxation of the sacro iliac joint rarely exists and that a great number of the cases of so called relaxation for which operations have been advised are in reality a toxic condition symptoms of which have localized in the overlying muscles and fasciae and are frequently referred to this joint This condition I have designated myofascitis Its treatment which is eradication of the focus of infection elimination medicinal and dietary has ordinarily no place in a surgical textbook but it is extremely important that the surgeon should rule out this diagnosis before undertaking operation to fuse the sacro iliac joint in cases which are doubtful Cases of gluteal myositis may result in so much spasm as to simulate either sacro iliac or lumbosacral strain The recognition of myofascitis as a clinical entity not only results in the cure of cases that have been persistently resistant to treatment or recurrence when based on empirical diagnosis but by eliminating the large number of pseudo sacro iliac strains gives us a more correct prognosis for real traumatic lesions of the lumbar spine Many cases referred to me for operation for sacro iliac strain have been entirely relieved of symptoms by treatment for myofascitis and unnecessary operation thereby avoided [10]

For the rare cases of actual pathological involvement I have devised three types of operation to produce fusion The operator should select the one best suited to the individual requirements

TUBERCULOSIS OF THE SACRO ILIAC JOINT

Tuberculosis of the sacro iliac joint is the most fatal of all joint affections and therefore an operative risk is more than justified But by the same token the operation should be so designed as not to exacerbate the condition and increase the risk by traumatization of the involved joint itself Therefore the extra articular method of arthrodesis is of as great or greater value in this joint than elsewhere

1 Bridge Bone Graft from Sacrum to Wing of Ilium (Specially Indicated for Tuberculosis or Some Other Infection) —For bony fixation of this joint the following technic has been devised by the author

With the patient on the face in the prone position and both spinal and tibial fields of operation prepared the posterior wing of the ilium and the upper portion of the sacrum are approached by a curved incision so placed that the line of skin sutures will not directly overlie the graft

[10] For details of treating this entity which has masqueraded under numerous diagnoses among them sacro iliac strain the reader is referred to the *American Journal of Surgery* III 523 533 1927

The first spinous process of the sacrum is split *en masse* with its enveloping ligaments and soft tissues, the cleft being made not vertically, but at right angles to the long axis of the spine. The upper half of the split process is left attached to the sacrum and unbroken; the lower half is fractured at its base and displaced downward. On account of its small size, the first sacral spinous process may be fragmented by repeated

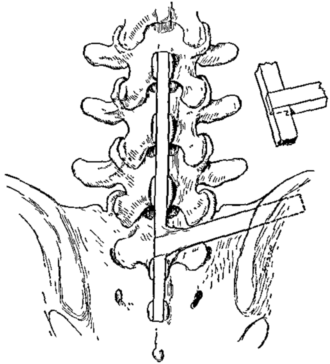


Fig 76.—Diagram from the roentgenogram of an actual case of tuberculosis of the last lumbar vertebrae and the right sacro-iliac joint The spine graft was inserted by the author's *regular technic for Pott's disease. The graft controlling the sacro-iliac joint was joined by a* carpenter's half mortise to the spinal graft (see small upper right-hand drawing). The callus uniting the two grafts is indicated. The graft was joined to the posterior wing of the ilium by shaping it into a wedge end which was forced into a split in the ilium made by an osteotome. From Albee, *Orthopedic and Reconstruction Surgery*, W. B. Saunders Co.

attempts to split it in equal halves, but this interferes in no way with the ultimate result if the fragments are left attached to the enveloping ligaments.

The periosteum of the posterior surface of the sacrum where the graft is to be contacted is split in line with the cleft in the spinous process and peeled downward with the sharp periosteal elevator. The underlying bone is then scarified over a considerable area for contact with the graft.

The mesial surface of the posterior wing of the ilium projecting beyond (toward midline) the sacro-iliac joint is developed and a cleft is

Fig 77 —Roentgenogram of a case of tuberculosis of last lumbar vertebra and sacro-iliac joint of which Fig 76 is a drawing *AB* is spinal graft *CD* is graft for fixation of sacro-iliac joint From Albee *Orthopedic and Reconstruction Surgery* W B Saunders Co

made by driving a ½ inch osteotome into it in a plane parallel with the prepared posterior sacral surface for the reception of the distal end of the graft. In making this cleft the handle of the osteotome is pressed

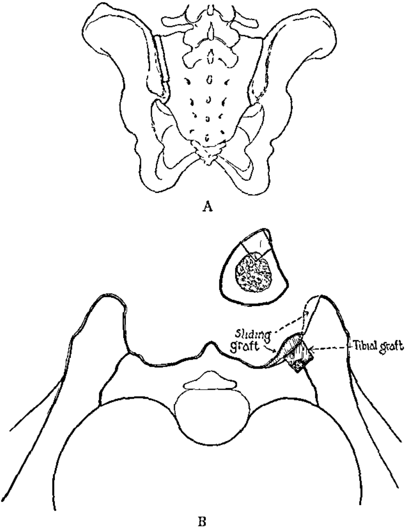


Fig 78—*A* and *B* indicate tibial inlay graft inserted into the sacro-iliac joint *for surgical* arthrodesis in a case of osteo-arthritis of this joint, failing to be relieved by conservative treatment. From Albee, *Orthopedic and Reconstruction Surgery*, W. B Saunders Co

down as tightly as possible against the posterior surface of the sacrum. The distal end of the graft is beveled in such a way that, on being forced into its bed in the ilium, its proximal (sacral) end is tightly coapted to the posterior surface of the sacrum (see Figs. 76, 77). The field of operation is then temporarily packed with hot saline compresses while the graft is being prepared.

The leg from which the graft is to be removed is flexed and the site of the proposed graft exposed by a wide curved incision so placed that the line of subsequent sutures will not overlie the site of the graft removal A bone graft ½ inch or more in width is removed from the antero internal surface of the tibia as described under the operation for Pott s disease Its distal (iliac) end is beveled on its periosteal side (which is to be the posterior side) so that it may be driven tightly into the cleft in the ilium by means of the author s bone peg set As much of the marrow substance as possible is left on the graft Numerous fragmented grafts obtained from beveling the iliac end of the graft and from the edges of the tibial gutter are placed about the points of junction of the graft with the sacrum and ilium

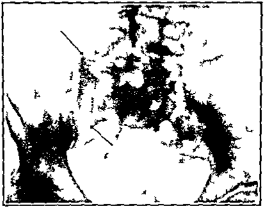


Fig 79—X ray of sacro iliac joint after bone graft fusion—illustrated in Fig 78

Ligaments and soft tissues are now united over the graft by medium sized kangaroo tendon and chromic catgut sutures, and the wound is closed with a continuous suture of No o plain catgut in the usual manner

Postoperative treatment consists of recumbency in bed for six weeks or longer

2 **Inlay Bone Graft into the Sacro Iliac Joint Itself (Indicated for Osteoarthritis of the Sacro Iliac Joint)**—The joint is reached through its posterior ligaments just to the inner side of the posterior wing of the ilium The cartilaginous surfaces of the joint with the underlying cortical bone are thoroughly removed by the osteotome and the author s motor burr or end mill The dimensions of the gutter thus formed are accurately obtained by means of compasses or inside calipers The graft is obtained from the tibia in the manner described in the preceding operation The graft usually measures about ½ inch in width and 2 to 3 inches in length The graft is then driven into place by means of a mallet and

the author's bone-peg set, and requires no retaining fixation sutures (Figs. 78, 79).

Postoperative treatment consists only of recumbency in bed for five to six weeks or longer.

3. *Inlay Bone Graft from Wing of Ilium Mortised into a Previously Inserted Spinal Inlay Bone Graft, for Combined Tuberculous Disease of Lumbar Vertebrae and Sacro-Iliac Joint, Author's Operative Technic.*—The posterior-superior spine, the wing of the ilium and first spinous process of the sacrum are reached by a curved incision. The spinous processes of the last one or two lumbar vertebrae are split, with their attached ligaments, by the author's thin, wide osteotome, forming a gutter to receive the ends of the graft. A cleft is made in the posterior wing of the ilium by driving a thin osteotome ½ inch in width into it just anterior and mesial to its postero-superior spine, and in a direction laterally *from within outward* (Fig. 76). *The lateral graft, which is later secured,* is formed with a wedge end to be driven into this cleft, the other end being joined by a carpenter's half mortise to the spinal graft.

If practicable, a surface of the sacrum is denuded to furnish additional contact with the graft. The wound is packed with a saline compress and with the patient still in the prone position, the leg is flexed and a graft of sufficient length removed from the crest of the tibia by the motor-saw (as described in the use of the bone graft in Pott's disease, except for the just mentioned wedge end) to furnish *material for the spinal graft and the lateral bridge to the ilium.* The width of the graft should be 3 times the thickness of the cortex. The thickness should include the whole cortex, periosteum, endosteum, and a small amount of the adhering marrow. The spinal graft is placed in its prepared bed and the ligaments are drawn over it by interrupted sutures of medium kangaroo tendon.

Before the kangaroo tendon sutures are drawn over the lower end *of the spinal graft, a segment is removed from its uppermost surface and into it one end of the lateral graft is half-mortised, and the other wedge-shaped end is driven into the cleft in the ilium prepared for its reception.*

The skin wound is closed and the patient placed on the back on a fracture bed for a period of not less than five weeks. There should be no necessity for further mechanical treatment.

(If both sacro-iliac joints are affected, a lateral graft is inlaid *from* sacrum to ilium on each side after the manner described *above for unilateral relaxation.*)

The *prognosis in tuberculosis* is better in adults than in children. The

outlook is more serious when there is abscess formation, especially in the presence of mixed infection Tuberculous sacro iliac joint disease is an extremely persistent affection When bony ankylosis of the joints occurs, the pain as well as the disease will disappear

Fig 80—Exposure for extra articular arthrodesis of sacro-iliac joint. From Campbell *Operative Orthopaedics* C V Mosby Co

Author's Note—In arthrodesing the joint, one has to choose between using local bone, or bone from the most favorable source, namely, the tibia I prefer to use at least part of the bone from the tibia, for two reasons (1) the relatively increased callus potentiality of tibial bone as compared with that from the sacrum or ilium, and (2) the anatomy of the joint is such that too wide resection of bone from the posterior wing

of the ilium detracts from a favorable mechanical situation. This is an operation of great magnitude and the very severe trauma to this deeply lying tuberculous joint is a real hazard (Fig. 80).

Campbell's Extra-articular Arthrodesis.— Fusion operations which enter the sacro-iliac joint are likely to be followed by secondary infection with discharging sinuses which may terminate fatally. The author employs a simple operation which is entirely extra-articular, thus avoiding any possibility of contamination within the joint. An incision is made

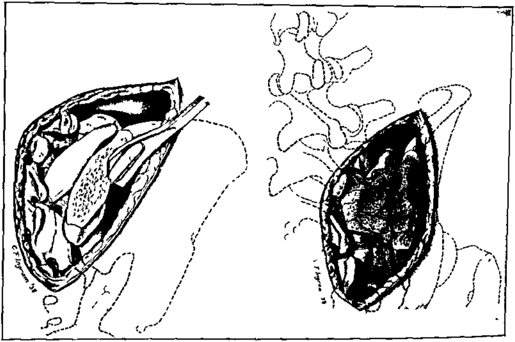


Fig. 81.—Inner table of ilium and adjacent posterior surface of sacrum denuded; graft from ilium countersunk into this area. Multiple small bone grafts fill intervening spaces From Campbell, *Operative Orthopaedics*, C. V. Mosby Co.

along the outer lip of the crest of the ilium from the posterior one third or one half to the posterior inferior spinous process (Smith-Petersen) (Fig. 81). This is carried down to the bone, where the periosteum is incised and elevated for a considerable distance, thus exposing the posterior portion of the dorsum of the ilium. The crest of the ilium is dissected and the adjacent fibrous tissue removed from the posterior surface of the sacrum beneath the region of the erector spinalis and sacrospinalis muscles. A portion of the crest is removed and preserved in a towel. The inner surface of the overhanging portion of the crest of the ilium and the adjacent posterior surface of the sacrum are denuded, thus making a raw

gutter parallel with the sacro iliac joint formed by the posterior surface of the sacrum and the inner surface of the ilium posterior to the sacro iliac joint Into this space is placed the graft from the crest of the ilium Multiple grafts or shavings are next secured from the dorsum of the ilium and placed into the gutter until the space is well filled The wound is closed in layers and the patient placed on a Bradford frame for a period of six weeks Frequently the lumbosacral joint must also be fused The graft from the crest of the ilium may be employed for this purpose

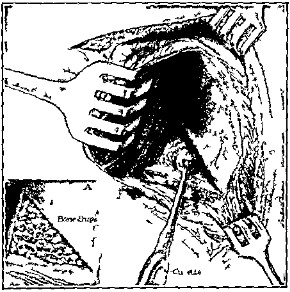


Fig 82 —Exposure of sacro iliac joint and removal of articular surface with curet The inset shows the joint packed firmly with healthy bone chips From Gaenslen Arthrodesis J Am M Ass Dec 1927 Vol 89

by inserting it into the spinous processes of the lower lumbar vertebrae and sacrum after the manner of Albee

Gaenslen Arthrodesis (Fig 82) —Through a curved incision the posterior third of the ilium is divided into an outer leaf which is reflected laterally with the muscles attached and an inner leaf which remains standing A triangle is marked out on the remaining leaf within the articulating area of the joint The bone is removed from this triangular area and preserved the articular cartilage from both the ilium and the sacrum is removed exposing the cancellous bone of the sacrum The bone fragments of the ilium which were preserved are packed into the triangular area and the outer leaf of the ilium replaced and sutured into position See also Fig 81

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CHAPTER IV

BONE GRAFT SURGERY OF THE HIP JOINT

A metamorphosis in the treatment of conditions of the hip has been wrought by the ever increasing application of surgical procedures to the numerous diseases and distortions of this joint Many of the conditions heretofore regarded as hopeless can now be overcome by means of surgery

It may be that the peculiar character of this joint has been the main obstacle to the development of surgical procedures for its diseases and disabilities Not only is it a ball and socket joint which increases the difficulties of adequate treatment but it is also a weight bearing joint and subject to the stresses and strains of active function for that purpose This joint is unique among the larger joints in that active weight bearing is dependent upon the coordinated pull of the most powerful muscles of the body upon physiological bone levers the most important of which is the neck of the femur In the absence of these bony levers their restoration further tests the versatility of the surgeon

Open surgery of the hip is principally a development of the past three decades Thirty years ago entering the hip joint surgically was thought to be fraught with great hazards Methods of procedure were relatively primitive and there was by no means the understanding of the underlying principles governing the successful treatment of lesions of the hip that we have today

The bone graft alone has played a major part toward this end

Approach.—The relatively small size of the hip joint no less than its position of great depth from the surface and its relation to very important structures all conspire to render surgical approach difficult This difficulty is well illustrated by the great number of routes which have, from time to time, been described by different operators Moreover, it is

evident that no one approach will satisfy all conditions; a route which is ideal for drainage of the joint may prove quite unsuitable for plastic work or *arthrodesis.*

The three principal methods of approach to the hip are the anterior, the anterolateral and the posterior. A fourth, the lateral approach, is not *to be recommended.* For all intra-articular work, I use the Smith-Petersen-Sprengel approach (anterolateral), the degree of lateral exposure depending on how far back the incision is carried along the crest of the *ilium. In* fractures of the neck of the femur, the vertical incision of Smith-Petersen with a very short posterior arm is preferred, the length of this varying with the obesity of the patient and the necessities of exposure in the particular case. Acute infections demanding drainage are the only condition for which I use the posterior approach.

Anterolateral Approach: Smith-Petersen-Sprengel Approach.[1]—*From a point three to four inches below the* anterosuperior spine, a vertical incision following the external border of the sartorius muscle is made upward to the spine of the ilium, thence carried backward, following *the iliac crest for two-thirds of its extent. By means of a sharp* periosteal elevator the gluteal muscles are reflected with the periosteum of the ilium adherent to them, until the capsule of the hip joint has been *exposed. No other approach can compare with this in the extent of* exposure and the facility it offers for all plastic procedures.

Posterior Approach: Kocher Approach.—Kocher makes an incision *from the posterior margin of the base of the trochanter major* upward to the posterosuperior angle of the trochanter, and thence to the posterosuperior iliac spine. The gluteus maximus is then divided in the line of its *fibers and the edges are retracted.* The gluteus medius is separated at its insertion into the trochanter major and turned upward. The pyriformis, obturator internus and gemelli are divided at their insertion into the *trochanter and turned inward.* The capsule is incised, and the superior half of the trochanter major divided from the main bone with a saw and turned upward *with its attached muscles. By adducting the diseased limb* across the sound one and rotating it outward, the head of the femur is dislocated posteriorly.

Langenbeck Approach.—In Langenbeck's approach *an incision* is made from the posterosuperior iliac spine to the posterosuperior angle of the greater trochanter. The gluteus maximus is divided in the line of its fibers and the edges are retracted. *This exposes the posterior* margin of the gluteus medius and the superior margin of the pyriformis. These are

[1] A similar approach was used by Sprengel about half a century ago in Germany, and later by Anderson in England.

retracted and if necessary the pyriformis is divided or loosened at its insertion This is a rapid and easy approach with little disturbance to the tissues The joint exposure is however limited as the superior margin of the tendon of the pyriformis is at least ⅛ inch above the posterosuperior margin of the neck of the femur This factor also makes drainage difficult

FRESH FRACTURES—NECK OF FEMUR

Bone Graft Peg —Although operative intervention and the implantation of metal nails or other foreign agents have been practiced in the treatment of fractures of the neck of the femur for over thirty five years yet there is no other fracture in which union fails so frequently The surgeon who is consulted regarding the insertion of a bone graft peg months after the fracture has occurred and when conservative measures have failed with much absorption of the femoral neck having taken place is impressed by his success at this late stage even though appreciating that an earlier operation would have saved months or years of convalescence or invalidism and would have contributed to a much better functional result

Statistics have shown that there is a mortality of approximately 20 per cent in aged patients with fractures of the hip joint and that of those remaining only about 50 per cent secure good bony union This appalling situation constitutes a real challenge to try to improve the treatment that has been used in the past The old dictum— Treat the patient and disregard the fracture —is not good advice The best way to treat the patient is to treat the fracture Pain is relieved as soon as the fracture is accurately immobilized and the patient has a much better chance to recover

In 1913 the author described (J B Murphy s Surgical Clinics at Mercy Hospital Philadelphia) the use of a bone graft peg for nonunion taken from the crest of the tibia of the same patient and in 1929 reported 91 7 per cent of proved bony union with this method Campbell at about the same time reported close to the same percentage of results and in 1932 in a series of 10 cases reported bony union in 100 per cent Most of these cases had been previously treated unsuccessfully by various mechanical methods (including metal nails)

A comparison of these figures with those published by the American Orthopedic Association in 1929 and 1930 is most instructive In a comprehensive study, they cited 41 1 per cent of proved bony union when

treated by closed reduction (patients under 60) and 64.8 per cent union by open operation (Smith-Petersen method) in patients of all ages.

Analysis of these statistics drives one to the premise that the requirements of this particular fracture are such that mechanical immobilization alone will not suffice unless supplemented by biophysiologic influences, from which the conclusion may be drawn that fracture of the central portion of the neck of the femur presents obstacles to union not present in other fractures, even in those situated less than 1½ inches away. I refer to fractures at the base or transtrochanteric region where union almost always occurs. Of these obstacles to union, the following seem to be the most important:

(*a*) Its location within a joint, so situated that a solution of continuity through it cuts off the proximal fragment from its principal source of blood supply, namely, that from the trochanteric region;

(*b*) The rotation of the fragment, avulsion or tear at the time of fracture of the ligamentum teres resulting in complete or partial obliteration of the blood supply even from this source, if one exists;

(*c*) It can be further claimed that from a mechanical standpoint this fracture is unfavorable because of the fact that the proximal fragment is practically a sphere in a slippery joint cavity and very likely to move at the slightest body movement or muscle spasm. Further, the fracture being in a joint, the fracture space is immediately filled because of a traumatic synovitis by synovial fluid which is inhibitory to callus formation. By the same token, there is no periosteum with its osteogenetic influences, nor is there blood supply coming to the point of fracture from the periphery.

It is impossible to speak in definite terms as to the relative amount of blood supply to the head and proximal portion of the neck of the femur, coming from these two sources, but it is certainly safe to say that considerably more than 70 per cent comes from the trochanteric region of the femur, and that in some instances it all comes from this source.

These statements have been confirmed by Wolcott,[2] who, in some very interesting work, has injected both the nutrient vessels of the upper end of the femur and those of the ligamentum teres with mercury in the cadaver and found that in a considerable portion of cases the small and unimportant blood vessels of the ligamentum teres did not extend into the head at all, and that the age of the patient had very little, if any, influence upon these findings.

Since callus potentiality has been proved repeatedly by my own animal experimental work and by that of others to be in direct relationship

[2] Personal communication.

with the amount of blood brought to the part, the importance of this consideration is evident

It is principally in this respect that this fracture differs radically from others In other skeletal fractures blood comes from every direction—from both fragments, and particularly from the blood supply of a collateral nature which is conducted to the point of fracture by the overlying adherent soft parts at the same time that these soft parts act as a scaffolding for the callus It is apparent that these conditions do not exist at the central portion of the neck of the femur It is believed that in fractures of the central portion of the neck of the femur that result in nonunion practically all blood supply is cut off except that which is available from the broken end of the distal fragment If the overlying capsule should be torn, there is little likelihood of the torn edges becoming sufficiently adherent to aid in the establishment of a blood supply of any consequence, especially since dense capsular tissue is unsatisfactory for this purpose An important consideration bearing upon this is the relative prognosis of an intracapsular fracture and one only ¾ inch farther out in the neck at the base of the transtrochanteric region, in which instance capsular and extracapsular tissue is attached to the distal end of the proximal fragment, thus serving to bring to it a sufficient blood supply Nonunion practically never occurs in such fractures

It is difficult to explain careful roentgenographic studies of nonunion of subcapital fractures on any assumption other than that of faulty blood supply The suggestion of erosion from the rubbing of one fragment end on another will not suffice, since in many instances of extensive disappearance of bone, no motion of one fragment on the other had ever been allowed to occur

It is my conviction that the blood supply of the ligamentum teres, if one exists, is almost universally destroyed at the time of the fracture in those cases coming later to nonunion This statement is based upon the experience of myself and associates at the operating table during the past twenty five years, during which time, in 467 cases, the femoral head has been removed while doing the author s arthroplastic reconstruction In only two instances has there been any bleeding of consequence from the stump of the ligamentum teres When one realizes that any extreme traumatic rotation of the head which should be expected at the time of fracture must tear this ligament, such findings should not cause surprise

In view of these biophysiologic conditions, it is apparent that the treatment should be largely directed in accordance with these requirements As the problem of nonunion is so much more difficult of solution than that of fresh fractures, it is consistent to maintain that the unusually

successful results and experience in the former (in author's series 91.7 per cent proved bony union) are eminently applicable to the problem of the latter. These results, coupled with a percentage of results *both in* fresh and ununited fractures far above those universally reported with purely mechanical methods when applied to fresh fractures, leads me to recommend for operative cases the employment of the autogenous tibial bone graft peg in all cases of fracture of the central portion of the neck of the femur, reserving the manipulative methods, Smith-Petersen nail and Kirschner and other wires for those cases where open reduction is not considered wise.

The urgent indication is to bring blood not only to the point of fracture, but to the anemic capital fragment. This objective can be accomplished in only one satisfactory way, and that is, by an autogenous bone graft so put in that it not only mechanically reduces and immobilizes the fragments, but also furnishes an osteogenetic callus-forming influence, serving at the same time as a vascular conducting scaffold. I have been employing the graft in this way and studying its results for twenty-five years, having first reported it in 1913.

The bone graft peg is the treatment of choice for selected cases of fresh fractures and for all cases of ununited fracture of the neck of the femur at any portion of the neck, where the capital fragment is of sufficient length to receive it favorably, and, if a manipulative method or metallic internal fixing agent has been employed, the first evidences of absorption of bone or nonappearance of callus should be immediately followed by this treatment.

TECHNIC—BONE GRAFT PEG OPERATION (ALBEE)

The joint may or may not be exposed in fresh fracture, but always in nonunion, by an anterior incision straight downward from the anterosuperior spine; a second incision is made over the great trochanter for the purpose of inserting the bone graft peg. The neck of the femur is inspected through the anterior incision. Eversion of the foot and limb causes the femoral fragments to separate anteriorly, and the ends of both are then thoroughly freshened with osteotome and mallet. The foot is then restored to the anteroposterior axis and sufficient abduction (about 30 degrees) and traction applied by means of the fracture table, to bring the freshened fragment ends into close apposition.

Attention is next turned to the short incision over the trochanter which has been carried down to the fascia covering the vastus externus. These structures are now split longitudinally so as to expose the lateral surface

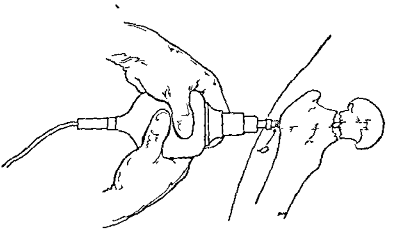

Fig 83 — Blind drilling of the neck of the femur for fresh fracture X ray used as a guide for angle of drill In elderly patients abduction cast applied first and operation performed through window in cast From Albee *Injuries and Diseases of the Hip* Hoeber

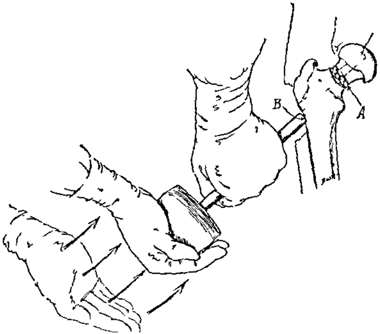

Fig 84 — Bone graft peg inserted and impacted by striking mallet head From Albee, *Injuries and Diseases of the Hip* Hoeber

of the great trochanter. The point of application of the drill lies ½ inch below the bony ridge to which the fascia overlying the vastus externus is attached. Since the direction of the drill must follow the central line of the neck, due consideration must be given to the angulation of the neck with both the axis of the femur and the vertical intertrochanteric plane. In the average adult, the neck makes an angle of 130 degrees with the

Fig 85—Ununited fracture of neck of femur. Preoperative x-ray. From Albee, *Injuries and Diseases of the Hip*, Hoeber.

femur, and 12 degrees with the vertical intertrochanteric plane, when the foot is in the anteroposterior plane.

With the motor drill held in the direction thus indicated, a hole ½ inch in diameter is drilled through from the lateral aspect of the great trochanter to the broken end of the distal fragment. This point is determined by instrumental palpation of the head of the drill between the opposed fragments. The reading on the drill (at *D*, Fig. 83) indicates the length of penetration through the distal fragment. With the drill head against the freshened end of the capital fragment, it is now carried into

this fragment until the reading shows sufficient penetration The degree of penetration through both fragments usually required is 7 or 8 cm (2½ inches) and is determined by a study of the roentgenogram The drill is left *in situ* while a graft is taken from the crest of the tibia of the same side

The tibia is exposed by a generous incision over its lower third This lower portion is preferred on account of the greater thickness and

Fig 86.—Same case as Fig 85 Postoperat ve x ray n ne months after bone peg operat on From Albee *Injur es and D seases of the H p* Hoeber

strength of the cortex A portion is chosen where the crest is straight and regular and the muscle and soft tissues are d ssected away With the motor saw longitudinal cuts are made on each side of the crest at a suit able angle with each other and at an interval sufficient to provide a peg ½ inch in diameter after shaping Two transverse saw cuts are now made at an interval equal to the reading on the drill and the segment loosened by means of an osteotome and gentle blows of a mallet The selected end of this segment is seized by two Ochsner clamps The other end is inserted in the pencil sharpener cutter attached to the dowel

shaper, by means of which the end is shaped to a blunt conical point favorable not only for subsequent engagement in the dowel tool, but also for reception in the drill hole already prepared in the femoral fragments. The pencil sharpener attachment is now replaced by *the dowel cutter* and the peg run through it.

During both of these shaping *processes, a drip of normal* saline is arranged to fall constantly on the tool, not only to hasten its cutting but

Fig 87—Same case as Figs 85 and 86 X-ray taken six years after operation. From Albee, Injuries and Diseases of the Hip, Hoeber.

also to prevent any possibility of undue heating. The saline solution also prevents dehydration of the graft by exposure to the air. Moreover, in the industries, either oil or saline solutions are used in the cutting of hard substances, for the purpose of clearing débris from the path of the cutting instrument, as well as for increasing the speed of cutting and for diminishing friction. The Bunnell's or Vall's guide may be used to aid in the proper direction of the drill.

The drill is now removed from the trochanter, and the peg inserted in its place and driven home with the bone drift and mallet. With the end

of the handle of a wooden mallet against the great trochanter (Fig 84) close to the peg graft I insure close approximation of the fragments by striking the palm of the hand or a sandbag against the head of the mallet

The deep fascia is closed by continuous sutures of No 1 chromic catgut and the skin with a continuous suture of No 0 plain catgut The limb

Fig 88—X rays (anteroposterior and lateral) taken immediately after insertion of nails showed apposition of fragments to be very satisfactory This x ray taken five months after operation shows non union and marked absorption of neck of femur and extrusion of nails From Albee *Injuries and Diseases of the Hip* Hoeber

is put up in a position of slight abduction, in a double plaster of paris spica extending to the base of the toes on the affected side and to the knee on the sound side for a period of eight to ten weeks Preoperative and post operative roentgenograms are shown in Figs 85-87

I wish to emphasize that the introduction of a nail or screw, or any material other than an autogenous bone graft, does not meet the requirements or overcome the physiologic and biologic barrier to union (Fig 88) Nails are foreign bodies and have no biologic or physiologic prop

erties, except destruction, as those of us who have been removing nails for years and observing their destructive influence can emphatically attest. It has been observed that advocates of metallic fixative agents are very loathe to diagnose a union before sufficient time has elapsed because of apparent x-ray evidence that union has occurred. In one recent case, three consultants declared from a study of the patient and x-rays, that union had taken place at the end of nine months; whereas within the next two months the fragments separated with ultimate extensive absorption of the neck (Figs. 93, 94).

Accuracy of fit of the autogenous bone graft peg is another essential (Figs. 89, 90). This can be accomplished only by the use of electrically

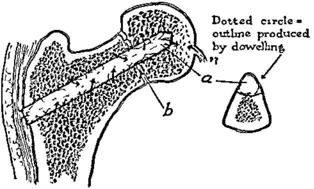

Fig 89—Diagram showing vascularization of anemic head of femur through blood vessels of autogenous bone graft peg, following fracture of the neck. From Albee, *Injuries and Diseases of the Hip*, Hoeber.

driven automatic machinery which brings about a fit commensurate with that of a glass stopper in a bottle. The insertion of the graft should not produce compression by too tight or inaccurate a fit, nor should there be a dead space, filled with air, blood clot, or tissue débris between the surface of the graft and the host bone tissues. In other words, there should be the closest coaptation of the haversian canals of the host and graft tissues so that early and complete vascular canalization of the graft will take place. Obviously, a graft of irregular cross-section is not desirable. The square peg in a round hole is a misfit here as in every other human endeavor. The early and complete vascularization which will occur best in an accurately fitted autogenous peg graft is not only essential to survival of the graft, but serves to carry blood and callus-forming material to the anemic capital fragment and to the point of fracture. Boiled bone is undesirable and in no sense a substitute.

Boiled bone, cow horn or ivory, because of their relative inherent weak-

ness, must be larger in diameter than a metal nail or screw and are, therefore, more undesirable because they displace more cancellous bone at the fracture junction. They do not serve as an osteogenetic scaffold or vascular stimulant to osteogenesis.

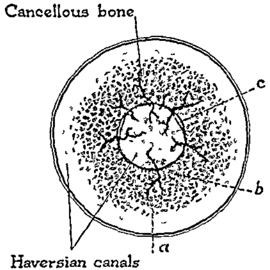

Fig 90.—Cross section of femoral neck with bone graft in center, showing new avenues of blood supply made available by bone graft From Albee *Injuries and Diseases of the Hip*, Hoeber

UNUNITED FRACTURES OF THE NECK OF THE FEMUR

In every case of ununited fracture of the neck of the femur in which the capital fragment has sufficient length to receive favorably a bone peg and is of sufficient length to furnish a lever to permit the abductor muscles to carry out their function, the bone graft peg is the preferable treatment. If this leverage is too short, the Albee reconstruction operation, which restores its length, must be used.

I want to emphasize that it is absolutely essential to enter between the fractured fragments of ununited fractures of the neck of the femur and to remove the synovial membrane that is almost always found on the ends of these fragments, and freshen them up in such a way that they will come into as perfect apposition as possible after application of the bone graft peg and artificial impaction

This is necessary for the following reasons:

1. It is important that the closest apposition without interposing synovial membrane or connective tissue be brought about between the

two femoral fragments with favorable conditions for union and establishment of blood supply.

2. As the ends of the bone are often irregular in shape and do not fit into each other, the surfaces should be transformed into perfectly plane surfaces so that they will fit with the greatest accuracy.

3. As it is believed that the synovial fluid is an inhibitor of bone growth, it is desirable also to furnish conditions which will permit the encroachment of callus between the femoral fragments to push out the synovial fluid, or better, to coapt the bone fragments so accurately that the synovial fluid is completely kept out. If the synovial fluid does not of itself have a particular inhibiting influence, it must be granted that the presence of any fluid inhibits and delays union.

RECONSTRUCTION OPERATION (ALBEE)

In spite of the wide applicability of the bone graft peg operation, there will always be a certain number of cases of long standing nonunion in which there has been much erosion because of lack of blood supply, ill-nourishment of the capital fragment and the eroding effect of ill-advised locomotion, in which one must employ a different type of procedure. For this type of case, I use a partial arthroplastic or reconstruction operation.

The approach is that devised by Smith-Petersen and is very similar to the Sprengel approach, with modifications to meet the requirements of this operation.

With the wide osteotome used for splitting the spinous processes in operation for Pott's disease, the muscles are stripped down from the side of the ilium by subperiosteal separation, and are separated from one another directly downward from the anterosuperior spine. The capsule of the hip joint is completely exposed. The joint is entered by a T-incision with the stem running directly downward along the neck of the femur. The head of the T is made about ¾ inch from the rim of the acetabulum, for the purpose of protecting this rim both mechanically and as to blood supply, and of furnishing a cuff of capsule to act as a lining of the outer portion of the joint and for the neck to rest against when the joint has been reconstructed.

Care should be taken to make the incision into the capsule sufficiently spacious so that the difficulty of getting the head out of the acetabulum will be minimized. The ligamentum teres is then severed by means of an osteotome (½ inch) thrust deep into the joint, and any adhesions of the capsule to the periphery of the head are carefully separated with a scalpel.

The limb is then strongly everted by adjusting the fracture table, so as to make room for the delivery of the head With two long ½-inch chisels or osteotomes, the head is pried out of the acetabulum, with a motion much like that used in eating with chopsticks, one osteotome is thrust into the inner and one into the outer substance of the head, and the two are used as levers against the soft parts to pry the head out of place A better technic is to use the forceps tongs, or a double cervical tenaculum to seize the femoral head and extract it The instrument shown in Fig 13 was recently designed for this purpose

As soon as the head is delivered, the patient's limb and foot should be inverted by the adjustment of the table, so that the foot points directly upward Then, with the scalpel, the soft parts are severed straight down on to the anterior surface of the trochanter (care being taken not to separate them from the bone) in the form of an inverted "L" In the clefts thus made in the soft parts with the scalpel two osteotomes are placed, one (1½) inch to make the bone incision of the long arm of the "L' and the other, (½) inch for the short arm These osteotomes are then driven in through the trochanter synchronously, so as to separate the bony lever intact and unbroken The broad osteotome is driven from above downward beneath the circumflex artery so as not to sever it, or the periosseous soft parts

The bone muscle lever (*a*), which should be about 4 inches long, is then pried outward by the osteotomes still in place and a greenstick fracture is produced at the lower end, thus separating the lever from the main portion of the trochanter Care should be taken not to separate the muscles and soft parts from the bony lever The cut made in and at right angles to the trochanter determines the amount of shortening of the limb and should not be made until the limb has been pulled down to the maximum by the fracture table, it is then made as high up in the trochanter as possible, in fact, just level with the rim of the acetabulum In this way, the minimum amount of shortening is produced and this is less than by any other operation yet devised

The last step is to greenstick fracture the bone muscle lever outward at its extreme lower end by using the wide osteotome (driven from above downward without separation of soft parts) Formerly, fragments of cancellous bone were removed from the cut surface of the trochanter and shaft by means of a curette, and placed in the angle of the gap thus formed The stump of the neck is then rounded so as to cause minimal irritation of the acetabulum

The assistant is directed to adjust the table so that the limb is brought to the limit of physiologic abduction at the hip, and at the same time the

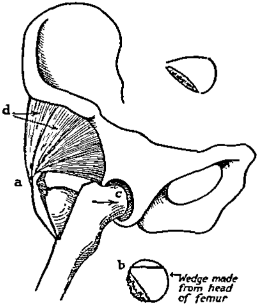

Fig. 91.—Author's method of reconstruction for ununited fracture of the neck of the femur. From Albee, *Injuries and Diseases of the Hip*, Hoeber.

Fig. 92.—X-ray showing result of technic illustrated in Fig. 91. From Albee *Injuries and Diseases of the Hip*, Hoeber.

upper end of the femur is lifted forward and guided into the acetabulum. The bone lever is thus automatically held by the limb posture in the oblique relation to the shaft of the femur with its upper end above and lateral to the rim of the acetabulum

My recent innovation is to shape the excised femoral head into a wedge (Fig. 91) by means of motor-saw, osteotome, etc, care being taken to remove all of the articular cartilage, and to place this wedge

Fig 93—Roentgenogram 9 months after reduction of fracture by the Whitman method See Fig 94.

in the angle between the shaft and the trochanteric lever. This has been found to be far superior to bone fragments for this purpose It produces a firm fit and immediately holds the bone-muscle lever in its proper relation without waiting for callus formation and reduces the time of plaster immobilization to three weeks (Fig 92).

The upper end of the bone-muscle lever is pulled forward and held with medium kangaroo tendon sutures placed in the surrounding attached soft tissues. The wound is now ready for closure. All dead spaces are overcome by means of continuous suture of No 1 chromic catgut.

Mechanical Action of Bone-Muscle Lever.— The mechanics of this operation may be further elucidated by a description of the mechanical action of the bone-muscle lever. The insertions of the short trochanteric or abductor muscles are carefully left intact on the trochanter or proximal end of the lever (Fig. 91). As the approach to the hip does not interfere with the innervation of these muscles, the ability to abduct, lost with the leverage action of the neck of the femur, is restored (Fig. 95). However, the lever substitution for the femoral neck is outside of the long axis of the femoral shaft, precisely as in the ox and many other

Fig. 94.—Same as Fig. 93. Separation of fragments 11 months after injury, during weight bearing

animals (Fig. 96). At the same time, when the leg comes to the midline or beyond, dislocation is prevented by the outward excursion of the proximal end of the lever and the resultant tension not only on the trochanteric muscles, but also on the soft parts surrounding them. This action holds the newly formed femoral head firmly in the acetabulum and prevents it riding on the rim of the acetabulum, leading to bone absorption of the rim and possible remote dislocation and pain.

In cases of arthroplasties of the hip in which the patient has weak abductor power following operation, I erect the same type of bone-muscle lever. In this type of case, a wedge graft taken from the side of the ilium is used to hold the bone-muscle lever in its new position. The

increase of efficiency of the abductors following this lengthening of the lever they act upon results in a much better gait, usually eliminating the positive Trendelenburg sign which so many of these patients have. This same principle is also used to elongate the lever at the top of the femur beyond its anatomical length in cases where the musculature has been weakened, as in infantile paralysis involving the gluteus medius, etc., muscles (see page 177).

Fig 95.—Photograph in case of ununited fracture of neck of femur of ten years' duration This patient had been compelled to use crutches for whole period of ten years Neck of femur had entirely disappeared and there was marked laxity of head at point of non-union This photograph, taken 18 months after operation, shows splendid result from reconstruction operation with bone muscle lever Patient was walking without crutch or cane, with painless, free motion From Albee, *Injuries and Diseases of the Hip, Hoeber*

At the conclusion of the operation, the leg is put up in a double spica, extending from the tips of the toes on the operated side, and to the tubercle of the tibia on the other side. The plaster is so moulded as to hold the upper end of the femur anteriorly and is kept on for a period of three and one-half to four weeks. The leg is then allowed gradually to resume the normal position The patient is persuaded to begin walking with crutches immediately after the removal of the cast, and daily massage and manipulation at hip and knee are at once instituted.

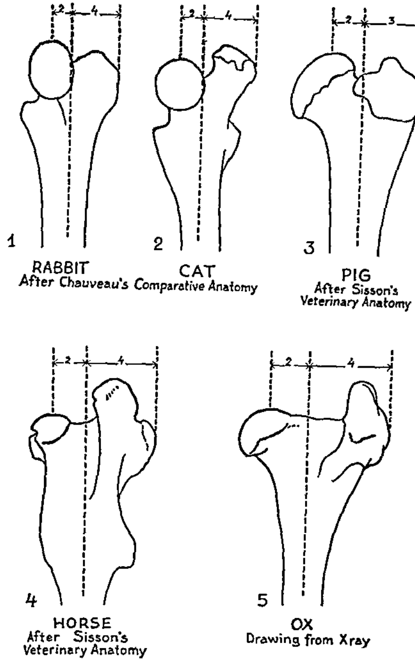

Fig. 96.—Upper end of femur of various animals discloses relationship of lever at top of femur with axis of shaft approximating very closely conditions brought about by my reconstruction operation. This is in contrast to condition brought about by Whitman and Colonna operations, in which outer end of lever arm is greatly depressed, thus shortening it and diminishing its mechanical effectiveness. Also in both these operations the great trochanter, which makes up a part of this lever, is removed. From Albee, *Injuries and Diseases of the Hip*, Hoeber.

The choice of operation is determined by the condition of the fragments and in some borderline cases the selection of operation cannot be determined until the head and neck of the femur have been exposed

CONGENITAL DISLOCATIONS

For purposes of treatment, cases of congenital dislocation may be divided into the following groups

1 Those in which it is possible either by bloodless or open operation to secure reduction with a stable hip

2 Those in which it is possible by closed or open methods to reduce the hip, but which, because of shallowness of the acetabulum or torsion of the neck of the femur, will not remain reduced

3 Those in which it is impossible to pull the head down sufficiently to reduce the hip In such cases, a shelf must be erected on the acetabulum In late years, I have included in this group cases that formerly I attempted to reduce at the cost of considerable trauma The unfavorable results in the way of ankylosis or limitation of motion at the hip have led me to believe that it is better to erect an acetabulum high on the ilium rather than to use so much force in reduction that one runs the risk of subsequent ankylosis

Infants up to Two Years of Age —Predislocation is becoming more frequently recognized in these young children The simple abduction treatment of Putti prevents dislocation in these cases Putti states that the early recognition and treatment of the condition is of importance not only for the prevention of dislocations but also because according to the experience of the Rizzoli Institute, congenital preluxation is the causative factor in 40 per cent of cases of arthritis deformans of this joint

Children from Two to Four Years of Age —Those children of about two to four years in whom manipulation easily reduces the dislocation, present such a perfect functional recovery that it is difficult to see how anything better could be desired The important point is that the reduction must be simple and easy of performance By this I mean that, under an anesthetic, traction followed by flexion, abduction, and rotation should be able to put the head of the femur back into its socket and that it goes back with a click which can be felt or actually heard. In these early cases there is one and only one serious obstacle to reduction, and that is the constriction of the capsule

In children, congenital dislocation of the hip should always be treated in the first place by manipulation under the guidance of roentgenograms, so that the head of the bone can be followed as it approaches and enters

the acetabulum. As a general rule, up to the age *of three to four years,* manipulation under roentgenographic guidance will effect this reduction, and then, if the limb is kept in an abduction plaster for about six to nine months, permanent recovery takes place, so that after a few years no abnormality can be detected in walking, and the roentgenograms show a normal joint, or one with a shallow socket.

Children from Four to Fourteen Years of Age.— In those children in whom *manipulation, aided by an anesthetic and* the x-ray screen, fails to reduce the dislocation, open operation is necessary. These children are generally aged from four to fourteen years. The hip is exposed by the Smith-Petersen incision. The capsule is cut open by a longitudinal incision over the femoral head, and if it is found that a narrow constriction leads into the acetabulum. The incision in the capsule is prolonged through this constriction, so that the socket is fully exposed. It is now quite easy, by means of manipulation aided by Murphy's shoehorn retractor, to place the head into the socket, but it generally becomes evident that it is not likely *to stay in this position because of the shallow character of the* acetabulum. At this juncture three courses may be followed:

1. The head may simply be kept in its socket by abduction of the limb fixed in plaster of paris, trusting to the pressure of the head to deepen the cavity in which it lies. This plan should be used only in those cases where the socket is reasonably well formed, as tested by its ability to hold the head when the limb is allowed to lie in the same line as the *trunk.*

2. The next and most obvious plan consists in deepening the acetabulum by means of a gouge or burr so as to accommodate the whole head, which is then pushed into the new socket and the capsule closed over it. This closure of the capsule will have to be in a transverse direction after the manner of a pyloroplasty, so as to overcome the constriction and at the same time shorten the capsule, tying the femur close to the pelvis. However, *in doing this, there is danger of ankylosis or limitation of* motion. This is accounted for by the fact that the acetabulum is robbed of its cartilage by the act of scooping out a new socket, while the head of the bone, which has been dislocated for a long time, has a very poor cartilaginous covering. This leads to a close fibrous union occurring between the bones. In the case of a unilateral dislocation, a firm but more or less fixed hip may give a good functional result, but if the deformity is bilateral, *then the double stiff hip will give a sadly crippled condition.*

3. The third available method is to leave the natural cartilaginous floor of the acetabulum and to try to hold the femoral head in place by constructing a bone graft shelf to the upper edge of the socket.

There is a growing tendency in the United States and Great Britain to favor open reduction not only when manipulative reduction has failed, but almost as a *routine, even in the youngest children* The decision *for* or against open operation depends very largely on the view held by the individual surgeon as to the degree of development of the capsular isthmus *in young children*, and the obstruction *this offers to reduction* The results of manipulative reduction prove conclusively that in the youngest children, at any rate, the reduction is complete in the vast majority Is it right to inflict the extra risk of open operation on all because very occasionally capsular *constriction, an abnormal ligamentum* teres, or some less obvious factor prevents a stable reduction being obtained by manipulation? Simple open reduction which comprises the *important* details of dividing the psoas *and enlarging the isthmus,* is unquestionably a useful procedure in favorable cases, which are rarely met with before the age of four, though more commonly afterwards

In recent years Galloway has been the strongest advocate of a more extended use of *open reduction in* all *children of two and one half* years of age Open reduction *per se* has no advantage whatsoever over the closed method, providing reduction is complete and permanent

The next question involves the importance of antetorsion, the influence *of this on the results,* and the advisability of correcting *this* deformity by osteotomy Opinions differ widely Lorenz, Bradford, and Gill regard it as unimportant, the first going so far as to say that its correction may lead to posterior subluxation On the other hand, most writers are not prepared to disregard it, though they differ as to how, when, and where it should be corrected Osteotomy is the usual method Soutter and Lovett say antetorsion improves with weight bearing, especially *after two or three years* Hibbs Calot, *and others do osteotomy in the* lower third of the bone, while Froelich snaps the atrophied femur over the edge of the plaster some months after reduction Krida also does a manual osteoclasis Schede and Codivilla use a nail driven into the trochanteric region to control the upper fragment As to the degree of antetorsion demanding correction, Bradford and Lovett say 90 degrees antetorsion is incompatible with normal gait and must be corrected Our experience is that if hips are reduced early, say *before the fourth* year, it is rare to meet with a case which demands osteotomy In the older cases, which should become less and less numerous, a degree of antetorsion of real importance, *i e*, over 90 degrees *is more common*, but still rare Failure of the upper lip of the acetabulum to grow out seems a far more potent factor leading to redislocation than any torsion deformity

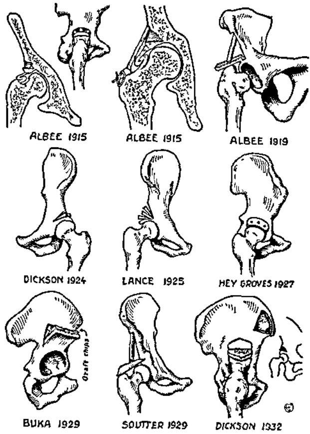

Fig. 97.—Various shelf operations for stabilization of hip in congenital dislocation. From Albee, *Injuries and Diseases of the Hip*, Hoeber.

in the femur. Therefore, it seems wiser to direct surgical treatment toward securing an adequate acetabulum.

The next problem is: Should anything be done, and if so, what, to the adolescent with this deformity who suffers little or no discomfort, and never complains of real pain? Fairbank has shown how far from perfect were the anatomical results after reduction in the older cases, even though *the head of the femur, or what was left of it, remained in the acetabulum.* Gross erosion from absorptive arthritis was present in most instances.

A bone grafting operation to make an upper lip for the acetabulum when the femur can be brought down to the requisite level, is the procedure of choice. Unless this can be achieved without undue trauma to head or acetabulum, it is better to leave *the head of the femur where* it is, or pull it down as far as possible with safety, guarding against

excessive tension upon nerves or blood vessels and then construct a bone graft shelf over it on the ilium

The author s operation for deepening the acetabulum by bone graft wedge offers success in a large percentage of cases (even in the 40 per cent of failures by the bloodless method) and produces a strong joint with good motion and without pain and shortening

TECHNIC—SHELF OPERATION

The shelf operation or formation of an artificial lip to the acetabulum is a most useful one for older cases and is being performed with increasing frequency

Many variations have been reported (Fig 97) to meet the exigencies of varying anatomical and mechanical conditions depending on whether or not the hip can be reduced or how high up on the ilium it must be stabilized

The operation is sound from the anatomical point of view the making of an efficient shelf is comparatively easy the difficulty lies in making the shelf at precisely the right level When relapse is seen to be occurring after manipulative reduction followed by prolonged fixation or when simple reduction offers but little hope of a cure—for example in a sub luxated hip at four years of age upward this operation is invaluable Fairbank believes the procedure should always be added to open reduction when the condition of the patient permits

Open Reduction —The open operation which affords the opportunity to study the pathology and which involves much less danger than forcible manipulative and mechanical procedures *may be used to advantage more often than it is customarily employed*

In most cases of old unreduced congenital dislocation or in cases in which reduction can be accomplished but cannot be held some type of shelving operation offers the best means of stabilization The procedure also offers the best chance for functional improvement The operation is indicated for old congenital dislocations in which the head is riding well up behind or anteriorly to the acetabulum on the posterior portion of the ilium as well as for cases of subluxation from infantile paralysis

The similarity of the various shelf operations is obvious the principle involved is the same in all There are two points in regard to the application of this type of operation which might be emphasized (1) The hip should be reduced or at least brought as far down as possible by heavy traction applied either before operation or at the time of operation or both and (2) the shelf should cover as much as possible of the

entire upper surface of the femoral head, but should not extend far enough laterally to interfere with abduction. It is not necessary to have the shelf jut out over the trochanter if the head is present.

The bony shelf relieves pain and fatigue in both young and old, helps to improve locomotion, and maintains the length of the leg.

Shelf Operation of Choice.—The joint is approached by the Smith-Petersen (or Sprengel) incision. With the single small motor-saw parallel cuts are made, about 1.5 inches apart in adults and less in children, through the outer table of the ilium in a position immediately above the acetabulum (Figs. 98-99). The upper ends of these saw cuts are connected by a horizontal cut made with the single saw. With an osteotome, this flap of bone is turned down so that it comes to lie snugly upon the capsule of the joint, which acts as a hinge where it is adherent to the ilium (see Fig. 99). The bone shelf still remains attached to the ilium in a hinge-like manner at its lower portion.

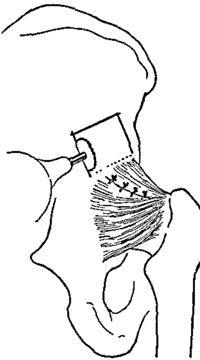

Fig 98.—First step in author's shelf operation for congenital dislocation of the hip. Rectangle of bone is excised from outer table of ilium. From Albee, *Injuries and Diseases of the Hip*, Hoeber.

With the small single saw or the twin saw blades, a rectangular block of bone of the same width is removed from the outer table of the ilium a short distance above the plate of bone already mentioned. This block of bone is completely detached, is placed as a strut or brace, and fastened by one or two kangaroo tendon sutures placed in drill holes (see *B-1*, Fig. 99). A double plaster of paris spica is applied, extending from the waist line to the toes on both sides with moderate abduction of both hips. It is usually necessary to apply traction to the limb postoperatively beneath the cast. This is accomplished by placing moleskin adhesive upon the inner and outer side of the thigh as well as on the upper half of the lower leg. As the plaster is applied, the lower ends of the moleskin straps are incorporated in it at a point about three to four inches above the ankle joint. Adequate traction is applied to the limb in order to lengthen it as much as possible. Following this, the countertraction is secured by moulding the plaster firmly against the plantar surface of the foot on

the unoperated side This traction is continued until the cast is removed at the end of seven or eight weeks, after which massage and passive and active motion are carried out to restore motion to the hip and function to the limb (Fig 100).

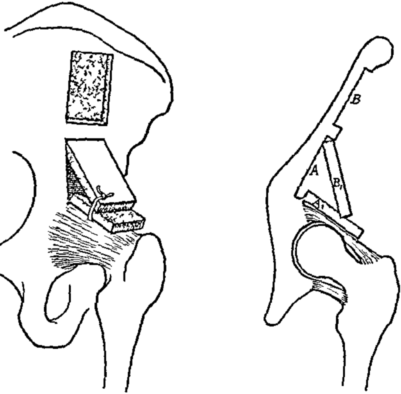

Fig 99—Bone graft A 1 for shelf is stabilized by bone graft B 1 From Albee *Injuries and Diseases of the Hip*, Hoeber

Steindler, Kulowski and Freund, in summarizing the end results of the treatment of congenital dislocation, say

We can say that the extreme optimism concerning results in the closed method, as it is shown by some German and Italian authors does not seem to be entirely justified Results become definitely worse with the duration of the observation period A systematic aftercare and long lasting follow up of the patients are absolutely necessary (roentgenograms should be taken at least twice a year in the first five years after reduction and at least once a year in the following years) Results of definite significance are given only by patients who after reduction in childhood are grown up to manhood and womanhood

The fact that beyond 5 years of age the satisfactory result rapidly decreased would indicate that the upper age limit for open reduction in general would be about 8 years. This agrees with Dickson, who recommends open reduction for all patients between 4 and 9

The significance of the palliative methods lies in their preventive effects on the functional difficulties coming on during and beyond puberty and on the late sequelae seen in unreduced dislocated hips in middle age, the secondary arthritis due to the static insufficiency.

It seems to us that from this point of view the simple shelf operations will undoubtedly gain in favor because of the lesser danger of operative failure and of postoperative

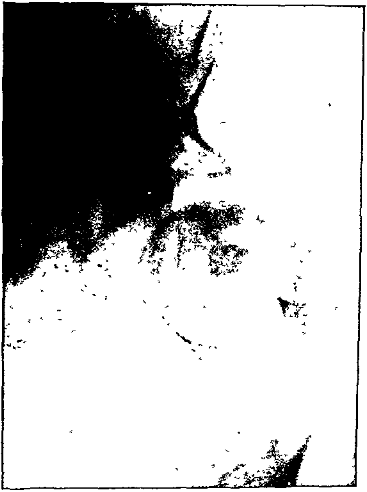

Fig 100.—Congenital dislocation of the hip; x-ray taken 5 years after author's shelf operation. From Albee, *Injuries and Diseases of the Hip*, Hoeber.

complications. In view of the increasing evidence of late degenerative sequelae of the unstable, unreduced hip, it may be assumed that the future will find the indication field of the palliative operation extended rather than restricted. Functionally available statistics show an encouraging percentage of acceptable results for shelf operations.[3]

[3] A. Steindler, J. Kulowski and E. Freund, *J. Am M. Ass*, 1935, 104:302.

PARALYTIC DISLOCATION

The indications for open operation in paralytic dislocations of the hip are

1 The inability to replace the head of the femur, owing to contracture of the soft parts, and

2 Repeated dislocation after reduction, owing to faulty development of joint structures (shallow acetabulum), or extreme relaxation of the capsule When thorough stretching of the contracted structures and reduction of the dislocation by the closed method fail, I use an autogenous keystone bone graft to deepen the overhanging rim of the acetabulum, and reef the ballooned portion of the joint capsule, thus gaining a stable and satisfactory joint without sacrificing any of the joint elements

KEYSTONE BONE GRAFT IN TREATMENT OF CONGENITAL AND ACQUIRED (PARALYTIC) DISLOCATION OF THE HIP (ALBEE)

All existing contractures having been overcome by forcible manipulation or open division, and the dislocation made easily reducible by long continued weight and pulley traction or manipulation under general anesthesia, the hip joint is reached by a Smith Petersen approach or an incision is made from the anterosuperior spine of the ilium to the great trochanter, then backward 1 to 2 inches in the direction of the ischial tuberosity The skin and subcutaneous structures are dissected back and the trochanter exposed The trochanter tip, with its attached muscles, is turned upward, giving a free exposure of the superior and posterior portions of the capsule of the joint, together with its attached portion of the superior and posterior acetabular rim This portion of the capsule is seen and felt to be lax if the head is in the acetabulum, and if the head of the femur is disarticulated it distends the capsule by pressure from beneath and further displacement of the head is readily felt as a rounded hard surface slipping about beneath the capsule

The amount of deficiency of the acetabular rim, as well as the degree of laxity of the capsule, can be very easily determined at this stage by direct palpation through the overlying capsule and manipulation of the limb Above the capsule attachment to the acetabular rim, the bone surface at the ilium is cleared of soft tissue, and with a thin osteotome the bone is incised just above the insertion of the capsule in a semicircular line, to conform to the natural curvature of the superior rim of

the acetabulum. This semicircular bone incision produces a strip of the upper curved bone margin of the acetabulum with its attached and undisturbed capsular segment. This curved acetabular bone segment is pried outward and downward with the osteotome to deepen the acetabulum sufficiently to offer an obstruction to displacement of the femoral head, *i.e.*, it is made to overhang and more securely grasp the head of the femur (Fig. 101). The downward and outward prying produces still

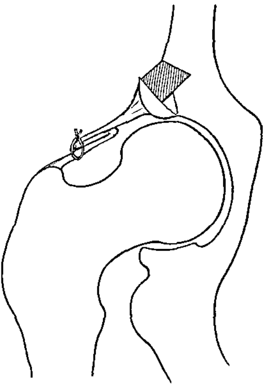

Fig 101—Deepening of acetabulum by building out rim with bone grafts. From Albee, *Injuries and Diseases of the Hip*, Hoeber.

more laxity and wrinkling of the capsular ligament. The slack is taken up by reefing the capsule with a row of mattress sutures of kangaroo tendon placed at right angles to the long axis of the neck of the femur. *The stitches are so placed as to make the reef of the capsule lie equidistant* from the two ends of the capsular bone insertions. This reefing avoids entering the joint, takes up the slack of the capsule, and at the same time helps hold the new-formed acetabular rim in position.

To fill in the bone gap produced by the prying downward and outward *of the curved bone rim segment,* and further to secure the permanent fixation of the new-formed acetabular rim, a segment of bone having a

triangular or keystone cross-section is obtained locally from the crest of the ilium or from the crest of the tibia, long enough (when cut into three or more portions) to fill in this gutter.

The keystone type of graft is self-retaining, and is held in place automatically and needs no pegs or sutures

The limb is placed in an abducted position and fixed by a long double plaster of paris spica reaching from the thorax to the toes on the operated side and to just below the knee on the other side. This spica is left on for six weeks, after which passive and active exercises are instituted, together with massage and guarded functional use of the limb

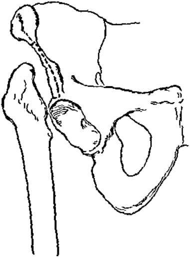

FIG 102

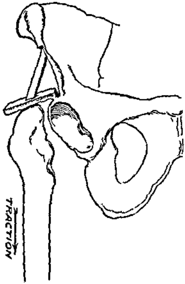

FIG 103

FIG 102.—Old acute epiphysitis, with destruction of head and neck and dislocation upward of trochanter From Albee, *Injuries and Diseases of the Hip*, Hoeber

FIG 103.—Erection of bone graft shelf over top of trochanter From Albee, *Injuries and Diseases of the Hip*, Hoeber

DISLOCATION FOLLOWING SUPPURATIVE ARTHRITIS

If a loose pathological dislocation has resulted and it is possible to pull the femur down, or if the case has been followed from the beginning and the length of the limb has been maintained, the riding up of the trochanter on the side of the pelvis has been prevented by the author in several instances by approaching the hip through the Smith-Petersen incision and turning down over the top of the trochanter a large area of the outer table of the ilium just above the location of the acetabulum, and fixing it there by means of brace grafts, also obtained from the outer table of the wing of the ilium (Figs 102, 103).

Fig. 104 A

Fig. 104 B

FIG 104 C

FIG 104.—*A* x ray *of tubercular h p in a boy of 12 years after six years of immob lization* in a plaster of paris sp ca and recumbency in bed In sp te of th s constant treatment there has been so much bone destruct on that the pelvis on the involved s de has been bisected and marked dis ntegrat on of the femoral head and neck and of the acetabulum has taken place

B same as 104*A* one year later

C same case as Fig 104*A* Fusion *resulting from* t b al bone graft Note large cavity has been filled w th *new bone induced by act ve bone forming propert es of the bone graft* From Albee Extra Articular Fusion of the Hip Joint for Tuberculosis" *Am J Surg* April 1939 49 1 187

EXTRA-ARTICULAR ARTHRODESIS FOR TUBERCULOUS DISEASE

Much discussion has taken place relative to the proper attitude of the surgeon toward operative interference with a tuberculous hip. During the past thirty years, the pendulum has gradually swung from the school of conservative abstinence from all operative measures to that of the school of radicals who advocate early surgical intervention. Conservative

Fig. 105—X-ray of tubercular hip with marked bony destruction in a child of 8 years. One year after onset and conservative treatment. From Albee, "Extra-Articular Fusion of the Hip Joint for Tuberculosis," *Am. J. Surg*, April, 1939, 44, 1:187.

measures should be given a brief trial in selected cases only in young children, and be supplemented early by surgery when indicated. In older children, adolescents and adults, operative intervention is especially indicated whenever bone destruction of any degree is shown by x-ray. The contrast in the result obtained by the operative *versus* the conservative method is strikingly demonstrated by the progress of the disease in two patients under my care at present, which bears out the cumulative experience of thirty years. The diagnosis of tuberculosis of the hip was made in one of these patients at the age of four and a single hip spica was applied to immobilize the joint. However, in spite of an intensive regimen of

heliotherapy, dietary measures, etc., the infection remained unarrested, destroyed the acetabulum so that the ilium was completely separated from the ischium and pubis without pain, and finally, resulted in penetration of the femoral head into the pelvic cavity (Fig 104) All this after six years of treatment in an accredited orthopedic hospital, so that no one can question the thoroughness with which these conservative measures were followed I first saw him at this time and performed an extra articular arthrodesis with tibial bone grafts

The second patient s story is a less gloomy one She came under my care only one year after the onset of the disease during which time continued immobilization in a cast did not influence the progressive bone destruction (Figs 105, 106) Fortunately, there was no shortening of the extremity, little atrophy of the muscles, and the ligaments of the knee joint were as yet unaltered I wish to stress that long continued immobilization and braceage—such as the first patient was subjected to—inevitably lead to laxity of the ligaments with resultant knock knee or recurvatum However, in the second patient, the rest of the limb was still normal and an extra articular arthrodesis with tibial bone graft was performed—resulting in a firmly ankylosed hip and arrest of the infection In less than a year, she walked without apparatus, crutch or cane, and returned to normal activity without any discernible alteration in length or contour of the limb becoming a carefree child once again When one contrasts this result with the six tedious years that the first child had to endure in a cast only to end up with a large cold abscess—a limb 2½ inches short, atrophied and with a deranged knee, the inevitable conclusion must be reached—that at the first sign of bone destruction as demonstrated by the x ray, the hip must be firmly ankylosed by surgical means

Operative Treatment —*Indications for operation* are briefly as follows An age at or beyond adolescence (As a rule, operation is contraindicated in young childhood and infancy except as an emergency, or when the disease is uncontrolled by conservative treatment) An extra-articular arthrodesis should be recommended in all children over ten years of age where the disease is progressing in spite of conservative treatment The resistance of the patient should be built up by heliotherapy and diet before and after the operation

Abscess formation, with steady advance of the disease as disclosed both by x ray and physical examination

Persistent loss of health

Ungovernable pain

Whenever there is contant relapse of the adduction deformity in spite of conservative measures to overcome it, such as traction in bed, braces, etc., after long periods of such treatment.

If the adduction deformity recurs following Gant's osteotomy, because of the hip not being completely ankylosed.

Fig. 106.—Same case as in Fig. 105. After extra-articular arthrodesis by two tibial grafts. Note the remarkable bone repair. Density has come back to both pelvis and top of femur. Spaces formerly filled with caseous material are shown to be completely obliterated with the ingrowth of healthy bone. This patient was so completely relieved of all symptoms and had gained so much in weight, that her mother brought her back from Mexico, one year after operation, to request an arthroplasty operation to restore motion to the hip. However, I did not deem this advisable at such an early date. From Albee, "Extra-Articular Fusion of the Hip Joint for Tuberculosis," *Am. J. Surg.*, April, 1939, 44, 1 187.

In adults even if the bone destruction is moderate.

Uncontrolled poor hygienic surroundings.

Procedures.—The operative possibilities consist principally of extra-articular arthrodesis by bone grafts, excision of focus when well localized and extra-articular, local curetting when sinuses secondarily infected exist, and amputation and arthroplasty rarely. Intra-articular arthrodesis is obviously inadvisable because of the danger of exacerbating the infection and its untrustworthiness if used alone.

Extra-Articular Arthrodesis.—Tuberculosis of the hip is a condition most unfavorable to intra-articular arthrodesis, either spontaneous or operative. The reasons for this are obvious: (1) inhibition of osteogenesis by the tubercle bacillus; (2) the peculiar anatomy of the joint frequently causing recession of bone surfaces from each other as bone destruction progresses, or following intra-articular removal of bone by the surgeon for arthrodesis purposes, because of the ball and socket contour of the hip joint (peripheral destruction of the femoral head causes it to become smaller, whereas peripheral destruction of the acetabulum causes it to become larger). Fig. 104.

Also, because of the anatomy and mechanical relationships of the hip and pelvis, as extensive destruction of bone progresses, the diseased bony surface of the femur and pelvis do not tend to approximate because of impingement of the inside of the trochanter against soft parts at and above the rim of the acetabulum Since the tubercle bacilli inhibit the active osteogenesis which would normally take place, dead spaces filled with caseous material are left between the bony elements, and spontaneous ankylosis and cure become improbable Even if intra articular arthrodesis is attempted, the possibility of causing metastatic infection or sinuses with secondary infection, the low osteogenetic potentiality of the bony elements of the joint and the consequent failure to secure fusion render the operation untrustworthy

Bracing in cases of extensive destruction and caseation, largely for the same reasons has been signally unsuccessful

Extra articular arthrodesis is a most satisfactory alternative By strongly bridging the joint with a tibial, femoral or iliac graft or grafts mortised into the bone elements on both sides of the joint, complete fixation is secured The immobilizing influence of union of the femur to the pelvis makes it unnecessary to enter the infected area (Fig 107)

Four Variations of the Author's Technic Adapted to Varying Degrees of Destruction —In an extensive experience with extra articular arthrodesis of the hip, I have been convinced more and more that it is distinctly advantageous to the surgeon to have more than one type of operation to select from in meeting the variety of mechanical requirements which I have above discussed Any proposed extra articular arthrodesis is best brought about between the great trochanter on one side of the joint, and the side of the ilium just above the rim of the pelvis on the other, and since the proximity of the trochanter to the side of the pelvis and the rim of the acetabulum varies widely in accordance with the degree of joint destruction and telescoping limb adduction and flexion, the operative technic must vary accordingly As in every surgical procedure, the simplest technic associated with the minimum of trauma and shock to the patient should be chosen, and also one which will interfere the least with a future arthroplasty, should the latter be desired and prove feasible

From the technical standpoint, cases suitable for extra articular arthrodesis of the hip can be divided into two groups, on the basis of pathological findings, and each of these subdivided into two types, as to the character of operation

Group 1 —In the first group, the destruction is moderate in amount

and the great trochanter remains widely separated from the side of the pelvis, so that a bone graft cannot be obtained from the side of the ilium or the immediate locality in sufficient length and strength to serve as a

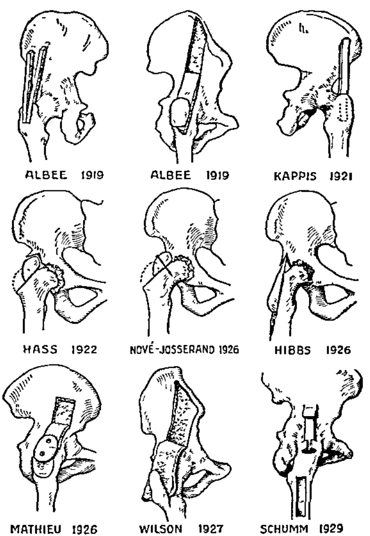

Fig. 107.—Some of the more important methods of extra-articular arthrodesis of hip. The purpose of illustrating various methods is to give the surgeon a choice of procedure in individual cases. From Albee, *Injuries and Diseases of the Hip*, Hoeber.

bridge for the extra-articular arthrodesis. Therefore, the surgeon is compelled to go to the tibia or the outer portion of the upper end of the femur for graft material, because of the necessity of obtaining not only long but strong grafts (Figs. 108, 109).

Technic for Group 1-A.—The patient is anesthetized to muscular

relaxation and placed upon the fracture orthopedic table. The surgeon forcibly corrects the adduction of the diseased hip by manual counter-pressure, placing one hand against the buttock and the other against the inner aspect of the knee. His assistant at the same time, by adjusting the fracture orthopedic table, places the well leg in the limits of physiologic abduction, and cautiously swings into a position of abduction the traction arm of the table holding the diseased leg. The amount of abduction in which the latter is placed depends upon the amount of bony shortening.

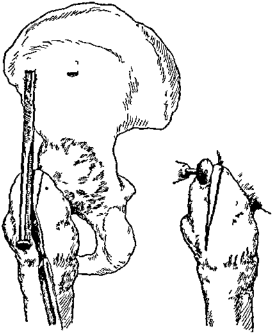

Fig 108.—Technic of arthrodesis of tuberculous hip with tibial grafts First step From Albee, *Injuries and Diseases of the Hip*, Hoeber

This method of correction, partly by the mechanics of the table and partly by manual pressure, is adopted in order to guard against overstretching the lateral ligaments of the knee joint.

A somewhat curved incision starting at the crest of the ilium, 2 inches posterior to the anterosuperior spine and carried down below the great trochanter, is made through the skin. The gluteal muscles are separated sufficiently to expose the side of the ilium at the points of mortise for the insertion of the proposed tibial grafts.

Because of the thinness and elasticity of the bone comprising the outer table of the ilium, a mortise suitable to receive the grafts can be satisfactorily made with a ½ inch chisel driven through the outer table of the ilium obliquely upward between it and the inner iliac table, with the han-

dle of the chisel in close proximity to the trochanter. With the cutting end of the chisel still in the mortise prepared by it, located 1 inch posterior to the anterosuperior spine, and 1 inch below the crest of the ilium, the handle is depressed onto the outer surface of the trochanter at its anterior border, and used as a guide for some cutting tool, such as the scalpel, to mark on the periosseous structures the line where the motor-saw is later to prepare a gutter for graft No. 1 (Fig. 108).

The same preparation is made for graft No. 2, except that the mortise in the ilium is made about 1½ to 2 inches posteriorly to the first one, and the scalpel mark is made on the posterior outer surface of the great trochanter.

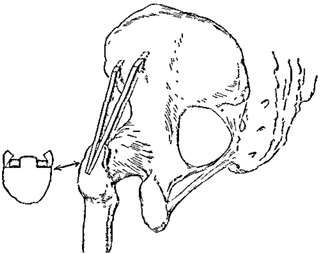

Fig 109—Second step Two tibial grafts are used to form a bony bridge from trochanter to ilium. See Fig. 110 From Albee, *Injuries and Diseases of the Hip*, Hoeber.

Saw cuts are now made ½ inch in depth with the motor-saw, following the scalpel marks just made on the trochanter. With an osteotome driven into these saw cuts, fragments of the trochanter are displaced with the periosseous soft parts as hinges, anteriorly from the saw cut for graft No. 1 and posteriorly from the saw cut for graft No. 2, so as to produce gutters to receive the two grafts.

The antero-internal surface of the tibia is then laid bare from the tuberosity of the tibia downward. With the motor twin saw set with the blades approximately ⅝ inch apart, a graft is removed by saw cuts made downward from the tuberosity of the tibia about 9 inches. With a small motor-saw, this strip of bone is then cut into two segments. The upper ends of the grafts are cut in an oblique way like the end of a chisel.

The upper end of graft No. 1 is inserted into the mortise of the ilium

with its lower end lying in the anterior gutter prepared in the trochanter The oblique surface at the upper end is outward With the author s bone drift or set (of which the carpenter s nail set is the prototype) placed on the trochanteric end of the graft the graft is now driven into the iliac mortise by blows of the mallet upon the bone set In this manner its trochanteric end is made to slide along the trochanter gutter and its proximal end to fit snugly into the mortise of the ilium

Graft No 2 is put in by precisely the same technic The firmer the grafts are driven into the iliac mortise the closer do they hug the bottom of the trochanteric gutter because of the obliquity of the cut end of the iliac end of the graft This plan of operation automatically immobilizes the grafts at both ends in a most gratifying way and makes immobilizing bone ligatures unnecessary (Fig 109)

Fig 110—Postoperative result 8 years after operation Influence of mechanical stress on graft may be noted Joint has been completely ankylosed by bone From Albee *Injuries and Diseases of the Hip* Hoeber

The soft parts with fragments of the trochanter are drawn over the ends of the graft by means of interrupted strands of medium kangaroo tendon The gluteal muscles are carefully drawn about the grafts by means of chromic catgut sutures

The skin is closed with continuous suture of 0 catgut Suture holes and the edges of the wound are puddled with 3½ per cent tincture of iodine (Fig 110)

Technic for Group 1 B—The upper portion of the approach for this procedure is similar to that described when tibial grafts are used In this instance the incision must extend generously downward 5 inches from the tip of the trochanter so as to give free exposure of the antero external aspect of the upper end of the femur The soft structures are separated, leaving the periosteum on the femur

With the motor saw and sharp ½ inch osteotome a strong graft about 5 inches long and comprising about one fifth the diameter of the shaft of

the femur from the tip of the great trochanter downward is obtained with a pedicle of muscle at its upper end. The lower end of the femoral graft is now swung anteriorly on the muscle and soft tissue pedicle at the upper end as an axis until its anterior end comes in contact with the side of the ilium. When the desired location on the ilium is thus determined, a flap or door of the outer table of the ilium is turned slightly upward and backward by means of the motor-saw and ½ inch osteotome, so that the upper end of the graft (formerly the lower end) can be thrust back-

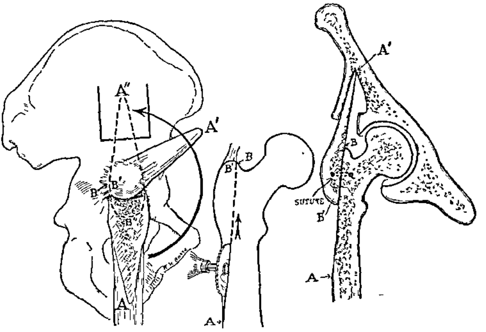

Fig. 111.—Diagram of method described for Group 1-B, tuberculosis of the hip. From Albee, *Injuries and Diseases of the Hip*, Hoeber.

ward beneath it (Fig. 111). Bone fixation ligatures are not necessary, as when the graft is jammed with a few blows of the mallet and bone drift, it is firmly placed and will not be displaced. The muscles and fasciae are now replaced over and around the graft with continuous suture of chromic catgut and the skin closed in the usual way.

The Hass' or Hibbs' procedure is somewhat similar to this method, except that Hibbs' method is not truly extra-articular, as both his diagrams and the description of this technic show that the neck of the femur is exposed and the cortex removed. The operation is therefore necessarily within the tuberculous area, which is to be avoided. Furthermore, it requires an extensive operative field, wide resection of muscles, and

much shock The procedure is the most difficult of the four types of technic presented I have so modified this operation that it is extra-articular, but the great trochanter and attached muscles are much more damaged than when the tibial grafts are used, and it leaves more unfavorable conditions for a future arthroplasty—a possibility which should always be borne in mind in planning an arthrodesis (Fig 112)

Fig 112.—Extra articular fusion with method shown in Fig 111 From Albee, *Injuries and Diseases of the Hip*, Hoeber

Postoperative Dressing—Extensive dressings of gauze and sterile cotton are applied, and then a plaster of paris spica from above the costal margin to the base of the toes on the operated leg, and to below the knee joint of the opposite leg, in a posture of abduction, sufficient, if possible, to overcome practical shortening

With the plaster still in a semiplastic state, it is carefully moulded over the operated area, for two purposes: to favor immobilization, and to aid in the control of bleeding.

The plaster on the uninvolved leg is removed at the end of five weeks. The remainder of the plaster is left alone until ten weeks from the time of the operation.

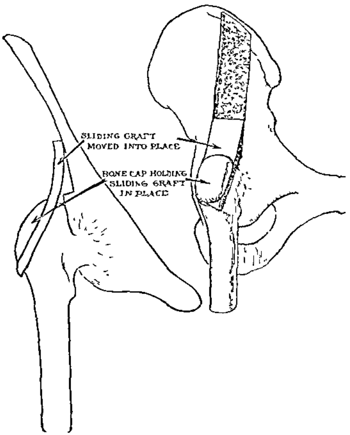

Fig 113—Sliding graft from ilium in place. From Albee, Injuries and Diseases of the Hip, Hoeber.

Group 2.—The operative technic for this group is illustrated by Figs. 113 to 116. The head and a large portion of the neck of the femur have been disintegrated with telescoping, causing the trochanter to become more or less closely approximated to the superior rim of the acetabulum and the side of the pelvis.

For convenience in discussing the operative technic this group may be subdivided into two types:

Technic for Group 2-A.—Group 2-A comprises those cases in which

the destruction has been so extensive that the trochanter has approximated the rim of the acetabulum to a sufficient degree within ½ inch or less—so that a sliding graft from the outer table of the ilium including the crest (Fig 113) is adequate to reach from the side of the ilium into the trochanter and also furnish adequate contact with these bony elements

Fig. 114—Arthrodesis of tubercular hip by author's method shown in Fig 113 From Albee *Injuries and Diseases of the Hip* Hoeber

and still allow the surgeon to keep outside the tuberculous joint The side of the ilium has already been laid bare by the Smith Petersen approach and furnishes a very satisfactory graft in that this outer table is not only curved so that it approximates the trochanter and ilium satisfactorily (Fig 114), but also enables the surgeon to secure as broad a graft as he wishes This technic is somewhat less difficult of execution

and consumes less time than obtaining a graft from the tibia or femur, as described under Group 1. The surgeon, after sizing up the mechanical conditions, may therefore choose this type of technic rather than the other two already described.

Technic for Group 2-B.—In certain extreme cases, Group 2-B, in which the trochanter is practically resting against the side of the ilium,

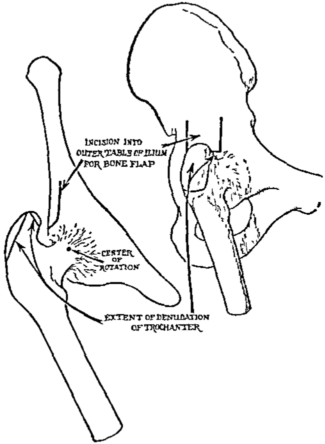

Fig. 115.—Arthrodesis of hip in advanced tuberculosis where trochanter approximates ilium. From Albee, *Injuries and Diseases of the Hip*, Hoeber.

and in which an intra-articular arthrodesis has been previously attempted, with complete removal of all tuberculous tissue, the following simple technic may be used: The trochanter may be denuded of its periosteum and periosseous structures, *both on its outer and inner surfaces* (Fig. 115). The outer table of the ilium just above the acetabular rim is then lifted externally, and the denuded trochanter implanted beneath the latter by swinging the hip into the abducted posture which automatically elevates the trochanter into the crevice thus made (Fig. 116). It may be

necessary to supplement this procedure by implantation of a graft obtained from the outer table of the ilium, higher up near the crest These very extreme cases are rare; I have encountered only two of this type This technic is partially intra articular

In any event, one should design the operative procedure so that the graft used will be firmly mortised into both femur and pelvis without

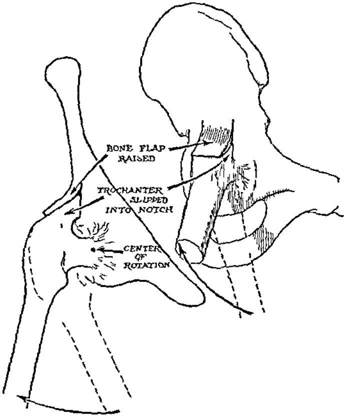

Fig 116.—Implantation of denuded trochanter under an osteoperiosteal door from outer surface of ilium Same as Fig 115 From Albee *Injuries and Diseases of the Hip* Hoeber

entering the tuberculous joint, and it will have to be left to the judgment of the surgeon as to just what technic should be chosen, always remembering that the simplest technic feasible will be most satisfactory (Fig 117)

Either of the procedures described under Group 2 is easier of execution than those for Group 1, providing the trochanter is near enough to the side of the pelvis so that it can be well carried out

Relative Difficulties of Technic—The simplest technic is 2 B, but for the reasons already discussed it is applicable only in rare instances

Fig. 117—Composite drawing *A*, outlines and dimensions of tibial grafts to bring about extra-articular arthrodesis of hip Illustration at left indicates influence of Wolff's law upon any stress-bearing graft Trochanter ends of grafts become much larger in diameter and stronger because more stress comes upon that portion of them. As stress increases from iliac ends toward trochanter, grafts coincidentally gradually increase their diameter, thus becoming cone shaped Drawing from x-ray taken twenty-two years after implantation of grafts. From Albee, *Injuries and Diseases of the Hip*, Hoeber.

Where the great trochanter is in close proximity to the rim of the acetabulum, the simplest bone graft operation possible for extra-articular arthrodesis is applicable; the sliding down of a broad graft from the outer table of the ilium into the split trochanter (2-A).

The tibial grafts (1-A) are next in order of difficulty (Figs. 109 and 117).

The most difficult operation, particularly as to extent of operative field and tissues involved is 1 B, the modification of the Hass Hibbs technic The original Hass Hibbs operation is not extra articular, but about 4 or 5 inches of the outer portion of the great trochanter and the shaft of the femur can be used to accomplish an extra articular arthrodesis This, however is an operation of great magnitude in that an incision has to be made from just below the crest of the ilium to nearly one third down the thigh in order to rotate the graft into position (Figs 107 and 111)

INTRA ARTICULAR ARTHRODESIS WITH SUPPLEMENTARY EXTRA ARTICULAR GRAFT FOR OSTEOARTHRITIS

The production of surgical ankylosis of the adult hip joint is indicated for the following conditions (1) marked pain (2) fibrous ankylosis following previous operation trauma, or from other causes (3) rare faction of the femoral head and neck in the adult, with inevitable or actual crushing of these structures

Author's Technic —Since I first reported the technic of arthrodesis for arthritis deformans (1908), I have modified the technic in several respects principally by the addition of either intra articular or extra articular grafts My early technic was as follows

The hip joint is reached by the Smith Petersen approach The capsule becomes visible and is incised A part of the osteophytes about the ace tabulum are turned upward with the soft tissues adherent to them since it is considered advisable to preserve as many of these as feasible on account of their potential bone producing power With the head of the femur *in situ*, approximately one third of its upper hemisphere is removed with a long osteotome or chisel, ⅝ inch in width in a plane nearly parallel with the long axis of the neck of the femur With the same instrument and a strong curette with a cross handle, the acetabulum is transformed into a flat surfaced roof against which the flat surface of the head is finally brought into firm contact by abduction of the thigh

Access to the joint is much facilitated by a position of *adduction* to the limb For the purpose of orientation an assistant is constantly kept in readiness to rotate the femur while the operation is in progress The bone is removed in such a way that the flat pelvic surface is tilted up somewhat mesially in order to produce a locking of the parts and to prevent any possibility of dislocation from weight bearing

If the adductor muscles prevent the required amount of abduction, an

open division of these muscles and tendons is made to permit the leg to be brought into the desired position. The acetabular and femoral head surfaces are brought into contact by simply abducting the thigh. In 1919, I described the intra-articular mortising operation supplemented by chip grafts around the periphery of the joint. However, I was occasionally disappointed in the failure of arthrodesis or a delay in the occurrence of the ankylosis. This experience, plus the realization that well-mortised

Fig 118.—Result of surgical fusion of the hip for osteoarthritis using author's technic of intra-articular arthrodesis with sliding bone graft from the ilium.

massive grafts are more trustworthy, induced me to modify the operation by sliding an inlay graft from the outer table of the ilium just above and including the rim of the acetabulum, downward into the cleft produced by the splitting *in situ* of the trochanter from above downward and outward with a $1\frac{1}{2}$ inch osteotome, with a minimum amount of periosseous and soft parts separated. The superior surface of the neck of the femur

is at the same time freshened by removing with an osteotome sufficient bone to make a flat surface against which is contacted the under surface of the iliac graft (Fig 118) See also Fig 113

Since changing the technic in this manner, the early fusion obtained and the absence of failure to secure ankylosis have been most gratifying The comparative experience with the old intra articular arthrodesis supplemented with chip grafts as compared with the massive inlay graft is the same as with all such operations performed upon any joint or location in the body, that is, it proves the untrustworthiness of small chip grafts as to their osteogenesis and their ability to fuse, and emphasizes the trustworthiness of the massive graft well incorporated by inlay or mortise into the elements of a joint to be fused

Soft tissues are sutured with continuous suture of chromic catgut, No 1, skin, with continuous suture No 0 plain catgut

A double plaster of paris spica cast extending to the toes on the operated side and to the tubercle of the tibia on the other side is applied, which remains on for a period of eight weeks

Following the removal of the cast, if roentgenograms and physical examination reveal solid bony fusion of the hip massage is started and the patient is allowed to bear weight as soon as his strength permits, usually at the end of five to seven days

GENERAL DISCUSSION OF ARTHRODESIS OPERATIONS

In ankylosis from suppurative arthritis, trauma or tuberculosis, if the conditions of the joint and periarthritic structures are favorable as well as the age of the patient, for future arthroplasty I so plan my arthrodesis that conditions are favorable for an arthroplasty at a later date *This is particularly true of the knee and the hip* both joints being favorable to arthroplasty, and the latter operation being of great advantage to the patient

At the hip, instead of using local bone graft material, I prefer to use tibial grafts so as not to destroy or impair the future function of the trochanteric muscles, *which is essential to the success of an arthroplasty And from a second standpoint,* I do a true extra articular arthrodesis so that the grafts can easily be removed at the arthroplastic procedure and will not interfere with the execution of the operation Further, a varying amount of trochanter ends are left in place with the gluteal muscles into which they are inserted, attached so that their functional control of the femur will be accentuated particularly in active abduction of the hip and weight bearing (Figs 120 and 121)

THE LEVER AT THE TOP OF THE FEMUR AND ITS SURGICAL ELONGATION

If one were to inquire of the average practitioner the function of the olecranon process at the elbow, I am quite certain he would, in a large percentage of cases, receive essentially the correct answer, namely, that active extension of the elbow joint is produced from the pull of the triceps muscle upon this lever acting purely as a lever. I feel there would be very little confusion as to the importance of the leverage action of the olecranon process in the kinesiology of the elbow and arm. The influence of function upon the lever at the top of the femur (head-neck-great trochanter) is of equal importance and identical in mechanical principle to that of the olecranon process and still, even few practitioners specializing in joint surgery have appreciated the importance of this action and its tremendous influence upon the pathology and function of the hip joint. In newly surgically made joints, a postoperative dislocation may occur because of the inadequate length of this lever. The pelvis may tip upward or the femur pull inward in adduction with varying resultant practical shortening of the limb, or weight-bearing weakness with a marked limp. Such limp has often been misunderstood for that of limb shortening and many patients have been brought to the author with a request that the limb be lengthened when there was no actual bony shortening of the limb whatsoever. The contrast in favor of the lever at the top of the femur is even greater, in that the olecranon process functions only to enable active extension; whereas the lever at the top of the femur helps to provide a mechanical mechanism for not only abduction, inward and outward rotation of the lower limb at the hip, but is essential to the stabilization of the hip joint and the active control of the weight-bearing relationship between the femur and the pelvis. There is one muscle inserted into the olecranon process and seven muscles inserted into the outer end of the lever at the top of the femur; namely, gluteus medius, gluteus minimus, obturator externus, pyriformis, gemellus superior, obturator internus and gemellus inferior.

With the sole exception of adduction, all other movements at the hip have to do, to a greater or lesser degree, with the pull of certain muscles upon the outer end of this lever.

Just as in industry or in every-day life, if the force available to be directed upon the end of the lever is inadequate, and it cannot be increased, then the only other recourse remaining is to elongate the lever so that the same available force will be adequate to the lifting of the

corner of a building or a rock. This same principle I have applied in the case of both the olecranon process and the lever at the top of the femur; that is, to lengthen these structures to the anatomical dimension when they have been shortened by disease, by trauma, by inadequate development, etc. In these instances, it is assumed that the muscle force is physiologically normal. On the other hand, when the muscle forces which normally activate these levers have been weakened from any cause

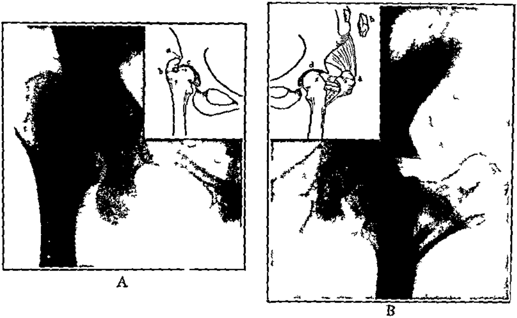

Fig. 119.—*A* preoperative x ray and key schema to illustrate cases of old reduced congenital dislocation of the hip with marked shortening of the lever at the top of the femur indicated by line at *b*. Bone block to abduction is indicated at *a* in schema.

B postoperative x ray of same case as Fig. 119 *A* showing removal of bone block to abduction as well as more than doubling the length of the lever at the top of the femur, *a d* rectangular bone graft *b* from outer table of ilium at anterior superior spine at *c*. From Albee: Reconstruction of Top of Femur (lever) or its Elongation in Paralytic Conditions, *Am J Surg* Feb 1939 43 2 416 421

whatsoever, particularly infantile paralysis, then it follows by the same token that the elongation of these lever structures is equally indicated. The results obtained by such surgical procedure have been most gratifying. This principle was first applied over twenty years ago to that of ununited fractures of the neck of the femur with extensive absorption of bone in my so-called *reconstruction operation*. A shell of bone obtained from the superior and outer surface of the great trochanter about 3½ inches long was turned outward with the muscle insertions undisturbed, and into the crotch thus made, fragmented grafts were packed, the pur

pose being to afford a longer lever for these muscles to pull upon, thus preventing postoperative dislocation, restoring abduction and active weight bearing.

Other cases in which this technic had been applied has been that of shortening of the femur from destructive lesions such as tuberculosis, where the disease has become cured, leaving a markedly short neck of the femur, or in cases of old reduced congenital dislocation of the hip with the same results (Fig. 119). Many of these cases have had marked adduction deformities with the resultant practical shortening, and particularly in the case of the healed tubercular hip, the teaching has been either to correct the adduction by Gant's osteotomy, or a correction at the hip joint supplemented by a fusion operation. In most instances, the latter destructive operation with loss of motion was found necessary because repeatedly the adduction slowly recurred. The reasons why this was so were not explained. The outstanding feature of these cases has been the shortening of the lever at the top of the femur. The adductor muscles function with their normal mechanical advantage, at the same time that their antagonistic muscles are markedly handicapped in that they are pulling upon a bone lever which may be as much as one-half its anatomical length. Is it surprising under these conditions, that the necessity for correction of an adduction deformity by osteotomy at the lesser trochanter should recur? The indications, as we see them now, in such cases are *to correct the deformity and then restore the abductor bone lever to its* normal dimension or even greater length. In some of these cases, both of congenital and from infectious origin, there has remained a bone block at the superior periphery of the hip joint which had been removed at the same time with the lengthening of the lever.

Another important indication is that in cases of arthroplasty to restore motion to a bony stiff hip joint where this lever had been shortened both by the destructive lesion which produced the ankylosis as well as the necessary removal of bone by the surgeon in modeling the new joint. In this instance, at the discretion of the surgeon, the lever may be lengthened at the primary arthroplastic operation, or it may be deferred to a later date. In border-line cases where there is doubt as to whether the lever is sufficiently long or not, it is urged that the secondary procedure be deferred until the function of the joint proves this necessity. This principle has been found applicable to cases of arthroplasty in a hip ankylosed by the author's method of extra-articular arthrodesis with tibial bone graft. A varying amount of the trochanteric ends of the graft are left in place so that the lever at the hip may be rendered more efficient (Figs. 120-122).

Fig 120—X ray to illustrate a common occurrence in tuberculosis of hip Case failed to respond to conservative treatment over a period of 6 years with resultant knock knee and knee laxity Extra articular tibial bone grafts relieved symptoms fused hip and cured condition From Albee *Injuries and Diseases of the Hip* Hoeber

My last application of this kinesiological principle has been demonstrated in cases of infantile paralysis where there has been a weakening of the group of muscles attached to the tip and outside of the great trochanter In this instance one would immediately reason that the lever is of normal physiological length but this has not been found to be the case at all The weakening of the trochanter muscles has resulted as one

might expect in the general lack of development of the whole upper end of the femur, and this has resulted in a diminution in the longitudinal diameter of this lever. Therefore, the indications for its elongation are double, namely, the muscle force which activates it has been lessened below functional capacity, and at the same time, the lever has become shortened. The surgical results from reconstructing this lever, as might be anticipated, have in many cases been brilliant.

Technic.—1. For many years following the introduction of my recon-

Fig. 121.—Same case as Fig. 120, after removal of most of tibial grafts and an arthroplasty restoring motion to within 20 degrees of normal. Stumps of grafts indicated by arrows were left to increase length of lever at top of femur for trochanteric muscles to pull upon, thus increasing strength of abduction and weight bearing. Great conservatism should be exercised in selecting such cases for mobilizing operation. From Albee, *Injuries and Diseases of the Hip*, Hoeber.

struction operation of the neck of the femur, published in 1919, I have devoted myself intensively to the development of the simplest surgical technic for all occasions in lengthening this lever. The availability of bone graft material is almost a determining element in the design of the special technic. The desire is to have a massive graft which will not only serve eventually to fuse in place and reconstruct the lever, but will immediately elongate the lever by its mass support. In the instance of the ununited fracture of the neck of the femur, the removed head of the femur serves this purpose admirably. Formerly, I always threw this away and used numerous small fragmented bone grafts, but during the past ten years or more, I have been able quickly to shape it into the form of a wedge using motor-saw and osteotome for this purpose (Fig. 91). This massive

wedge, when properly placed immediately supports the lever in its elongated state and serves forthwith to prevent the dislocation of the newly formed femoral head from the acetabulum Because of its extensive mass it allows ample leeway in shaping the desired size wedge and only three

Fig 122—Same as Figs 120 and 121 showing satisfactory painless motion at left hip From Albee *Injuries and Diseases of the Hip* Hoeber

weeks of postoperative immobilization has been necessary Because of this free joint motion is much more easily restored When fragmented grafts were used it was even necessary to immobilize by double plaster of paris spica cast for a long period at least eight weeks in order to allow time for the grafts to unite firmly and consolidate the new lever so that postoperative dislocation of the newly made hip joint would not occur

2 In cases of shortening of the neck of the femur from ancient cured disease or congenital malformation or from former arthroplasty where this lever has been shortened both from the destructive lesion that pro

duced the bone tuberculosis, plus the removal of bone by the surgeon made necessary in modeling a new joint, the bone graft material can be obtained from the side of the ilium, always high up at the crest, so as not to disturb either the muscular structure or its elevation. It can also be obtained from the antero-internal surface of the tibia, the most satisfactory storehouse of bone graft material. At the discretion of the surgeon, this lever may be elongated during the primary operation to produce motion in a bony stiff joint. In this instance, the side of the ilium

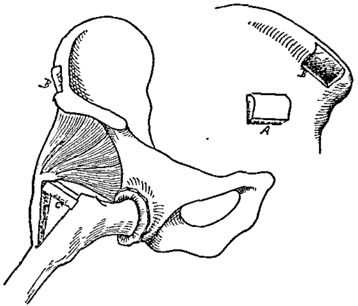

Fig. 123—Author's method of elongation of the hip lever with a rectangle of bone excised from the ilium See Fig 91. Employed in the insufficiency of the lever following arthroplasty, in infantile paralysis, and congenital dislocation of the hip.

has been already laid bare and therefore the material for the elongation of the lever can be easily obtained. Formerly, I obtained the grafts from the side and crest of the ilium in the form of two "pieces of pie" (segments of a circle) consisting of the outer half of the crest and the outer iliac table of proper shape and size to fill in the bony wedge cavity produced by the turning out of the shell bone from the tip and side of the great trochanter. These may be fastened together with a bone graft peg.

The technic, however, which I employ at present is to obtain the graft in the shape of a square or a rectangle from the outer table of the ilium, including the outer half of the crest. This is placed as shown in Fig. 123, and immediately supports firmly the lever in the elongated state.

The technic for infantile paralysis is precisely the same (Fig. 124).

However, one caution should be firmly adhered to,—that is, if the graft is obtained from the outer surface of the ilium, it should be from the extreme upper anterior border, including a portion of the crest for the purpose of not disturbing the weakened muscles more than is absolutely necessary

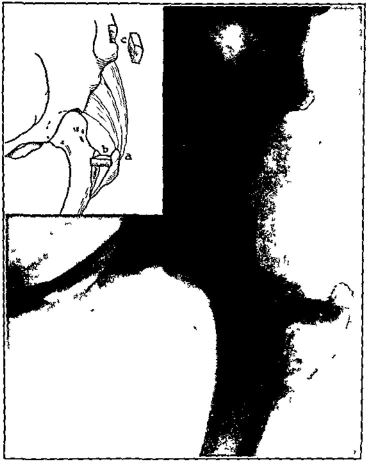

Fig 124—Demonstrates the lengthening of the lever at the top of the femur by more than 50 per cent in a case of infantile paralysis with weakened abductor and weight bearing muscles From Albee, "Reconstruction of Top of Femur (lever) or Its Elongation in Paralytic Conditions," *Am J Surg*, Feb, 1939, 43, 2 416-421.

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CHAPTER V

BONE GRAFT SURGERY OF UNUNITED FRACTURES

Ununited Fractures —There is only one way to treat nonunion and that is by open operation The site of fracture must be exposed carefully so that the conditions inhibiting union may be recognized and suitably dealt with Theoretically, nonunion might result from the failure of any one of the stages of union—practically, union is more likely to fail at some stages than at others

Etiology —1 The granulation tissue may fail to bridge the gap (*a*) because of the interposition of tissue which the granulations cannot penetrate, (*b*) because the fragments are so displaced that the two areas of granulation cannot meet, (*c*) because too extensive removal of blocks of living bone after fracture has left the fracture surfaces too far apart

2 The granulation tissue may degenerate into scar tissue before ossification has been established If the formation of the granulation tissue is slow and its nutrition is not well maintained, the stage of contraction is likely to be precipitated The osteoblasts under such circumstances are poorly nourished, and they multiply slowly and secrete pre osseous substance and phosphatase slowly, sufficient lime salts cannot be deposited to bridge the gap before the stage of contraction of the granulation tissue sets in

3 The early granulation tissue may be so disrupted by manipulation, or inadequate immobilization and the stress exerted on them by the muscles after recovery from anesthesia, that the process of capillary budding ceases or becomes inadequate for the needs of connective tissue union and ossification As Kellogg Speed puts it, "The vascular out growth is disrupted, disheartened, and ended" Robinson discusses the danger of movement of the fragments and its effect on granulation tissue

He shows how opposed to the physiological principles of union Lucas-Championnière's teachings were in this regard.

4. Similar disorganization may be produced by rough manipulation after the formation of soft callus. While nature may be expected to persist in spite of her first efforts having been undone, it is probable that, in cases unfavorable for other reasons, the effort will not be repeated. When such trauma results in the rupture of vascular continuity between intact bone and a large mass of granulation tissue or soft callus, these become actual obstacles to union until vascular continuity with them can be re-established. In essence, a comminuted fracture now exists. If the *fragment of new tissue is displaced, it may constitute an insurmountable* obstacle.

5. Since blood may be brought to the area of fracture by periosteum (from the muscles), by the nutrient artery, through the marrow, and by the haversian system, it is not likely that all sources will fail. If the laceration of muscles is so great that the periosteal circulation is diminished, or if the nutrient artery is ruptured, or if the pressure of excessive hematoma or congested soft tissue on the area of fracture is so great as to impede the circulation to it, any one of the other causes may be sufficient to defeat the efforts at union.

6. Infection is a cause of nonunion, the influence of which has, in some respects, been much discussed. Local acute inflammation of certain types is a stimulus to the formation of granulation tissue and even of callus. One has observed the stimulation of union following erysipelas about a compound fracture. Still, the destructive effect of infection on callus and formed bone is not to be disputed. When inflammation results in extensive thrombosis, necrosis must ensue in bone as in any other tissue.

A destructive type of low grade infection is often associated with the presence of foreign bodies in the fracture zone. It is a common experience to find pus about metal plates and extending between the fracture surfaces. In such cases, if granulation tissue has been thrown out by the bone elements, it has been destroyed and no evidence of beginning union is evident.

7. Lane's plates, especially when incorrectly applied, may cause nonunion. At best, the necessary stripping of the soft parts leaves the ends of the fragments isolated and impairs the circulation, especially to the periosteum. The ends of the fragments are thus robbed of nourishment and may even be devitalized. If the bone ends are distracted, the stimulation of mutual apposition and fracture surface stress is lost; moreover, the greater the distraction, the wider the space to be filled with granulation tissue and the greater the danger of the connective tissue contracting

to form a vascular scar tissue before ossification is complete The proneness of low grade infection to set in in the presence of foreign bodies has been referred to In a surprising number of cases when removing metal plates in nonunion I have observed a thin seropurulent fluid (due to the foreign body irritation) between the fragments and I have considered such exudate a serious obstacle to the formation of granulations and to ossification (Fig 125)

A B C D

Fig 125—*A* unsuccessful application of Lane plate in fractured tibia
B large defect following removal of plate and sequestrum
C bone graft (*AB*) removed from other tibia and inlaid across fracture
D one year after operation showing complete restoration of shaft of the tibia

8 A rarer cause of nonunion is absorption of solid callus before restoration of trabecular alignment has been completed Manual examination of the site of fracture even the x ray study of it may reveal no occasion for caution If more function and stress are permitted than the new bone can accommodate itself to the new structure may be absorbed Since this accommodation consists of the absorption and reconstruction of trabeculae and rearrangement of the vessels of the haversian system through the callus and since these depend upon the abundance of blood

supply, it is clear that, if vascularization is restricted or circulation impeded, absorption of callus is more likely to occur when function and stress are permitted. It is one of the purposes of massage to ensure circulation proportionate to the demands of the stress of early function.

CONGENITAL NONUNION

The reparative response after fracture seems strikingly independent of systemic conditions. It does not vary directly with the general state of health, nor is it affected, with any constancy, by diseases characterized by malnutrition or general debility. There is a general feeling that old age must cause inhibition of bone growth. This is not clinically a fact. Bones of aged people seem to unite with the same facility as they do in the young. By all odds the most stubborn nonunions are in the infant or young child, particularly if the fracture was intra-uterine. Some surgeons of considerable experience have gone so far as to recommend amputation in all cases of intra-uterine fracture. My statistics show that in such cases, by instituting operative treatment in conformity with the physiological and biological principles of bone repair, I have succeeded in inducing union in about 60 per cent.

Illustrative Cases.—This was a case of intra-uterine fracture of the left tibia and bowing of the fibula. Various operations had been performed but union was never permanent. Wiring and bone grafting had been tried, both separately and in combination. Figure 126 *A* and *B* illustrate two of these attempts when the child was three years old. I saw the child when she was six; the nonunion and bowing are shown in Fig. 126 *C*. I used a double-wedge-end inlay graft taken from the child's other tibia. I also performed osteotomy to straighten the fibula. Figure 126 *D* and *E* (taken a month apart) show the result two years later. Four years after this operation, the child was reported to be active as the normal child, and it was considered that functional restoration was complete.

Five years after the operation, the child slipped and the tibia fractured in its lower third. Reunion was effected by the use of a plaster splint, but refracture occurred three months later. Plaster splinting again brought about union. The condition 7 years after the operation is illustrated in Figure 126 *F*. Now, 14 years after the operation, the function of the limb is excellent and union is solid.[1]

The causes of nonunion may also be grouped into those concerned with the formation of granulation tissue and those concerned with the ossification of that tissue. Bancroft makes so little of the second group of causes that he states: "If a fracture is immediately treated in a manner

[1] *Surg, Gynec. & Obst*, 1930, 51:289-320.

which will replace as far as is feasible the fractured ends in suitable apposition and allow for organization of the clot and ingrowth of granulation tissue with its accompanying vessels, repair will inevitably follow." Clinical experience in cases of multiple fracture supports Bancroft's belief that the causes of failure of union are local; one fracture may unite and another fail Still, I would not make so sweeping an assertion as Bancroft's. It is true that investigation of one systemic disturbance, that of the calcium and phosphorus content of the blood, has been inconclusive, but since, as I have pointed out, nonunion may be the result of

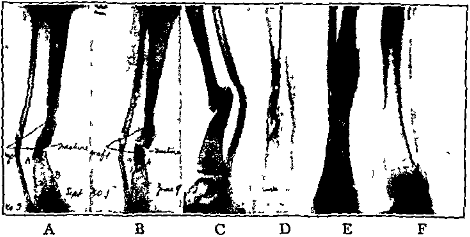


Fig 126—Case of intra-uterine fracture of tibia and fibula *A* and *B* show the results of bone grafting and wiring *C* shows the condition at the time of first observation *D* and *E* were taken 2 years after the insertion of a double wedge end graft and osteotomy of the fibula by the author *F* shows the ultimate result 7 years after fracture From Albee, "*Principles of Treatment of Non-Union of Fractures,*" *Surg, Gynec & Obst*, Sept, 1930, 51, 3.298 By courtesy of *Surgery, Gynecology and Obstetrics.*

failure of the preliminary stages of healing and may thus have no connection with ossification, conclusions from observations of a mixed group are of necessity contradictory and erroneous

The end-result in nonunion varies with the fate of the granulation tissue If it has formed a complete bridge but has degenerated into fibrous tissue there may be a dense mass of scar tissue between the fragments, constituting fibrous union If it has been largely destroyed by pressure and movement of the fragments, the space it occupied may be filled with a pseudosynovial fluid enclosed in a capsule which represents the peripheral portion of the original granulation tissue. This is the pseudarthrosis. In other cases there is no evidence that granulation tissue ever bridged the gap, the fragments being entirely displaced and disconnected.

OPERATIVE MEASURES

The operative measures instituted should be those which the surgeon believes will be the most likely to result in union. Different methods are employed, varying from the purely mechanical to those which are based on the most accurate conception of the process of union which physiology and biology can supply. In between the two come various methods which violate one or more of these fundamental principles; one sacrifices immobilization; another takes no account of the necessity for optimal vascularization; according to another, boiled bone is a graft or differs in virtues and drawbacks from other inanimate foreign material.

Preoperative Management.—If the history suggests the presence of latent infection, it is better to disclose it, by means of deep massage with manipulation of the fragments, than to have a recrudescence after the insertion of a graft. The infection is eradicated by surgical means and grafting not undertaken until the lapse of sufficient time after healing.

If, in the survey of the case, the presence of extensive scar suggests that the graft cannot be surrounded by well-vascularized tissues, the scar should be removed and replaced by an ample pedicle graft usually taken from the other limb. The bone inlay operation should not be undertaken until at least one month after the completion of the pedicled graft procedures.

The immediate preoperative care is of the greatest importance. It is carried out for twenty-four to forty-eight hours. In my own practice the iodine preparation is always used.

Technic.—*The Inlay Bone Graft Operation.*—In all cases in which it is necessary to have the limb under mechanical control, the patient is placed upon the Albee-Comper fracture-orthopedic table for management, not only throughout the operation, but during the postoperative immobilization by plaster of paris. The patient is, of course, anesthetized to the point of muscular relaxation, spinal anesthesia being used frequently for the lower extremities.

The fractured area is exposed by a generous skin incision. If scar is present but not too extensive, the incision should be made through healthy tissue when possible. The incision is made large enough to provide access to the pseudarthrosis without undue traction on the soft tissues. When the fractured bone is superficial, as in the case of the tibia, the incision is made lateral to the intended site of the bone insert. The skin and subcutaneous tissue are retracted and the bone ends are delivered and freshened with osteotome, motor burr, or saw. Anemic scar tissue is care-

fully dissected away so that vascular tissue will come in contact with the graft The periosteum is divided with a knife longitudinally over the bone to be removed in making the gutter for the bone insert Periosteal flaps are turned back to either side and the bone exposed

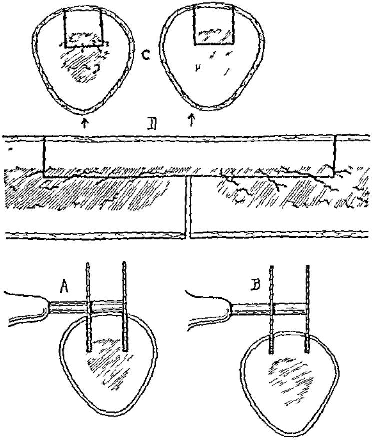


Fig 127—Method of preparing graft bed and inserting graft The longitudinal section shows the graft in place each element making close and intimate contact with a similar layer in the host. The nutrition of the graft diagrammatically represented comes from the marrow and periosteum of the host (The linking up of the two vascular systems by means of granulation tissue cannot be represented because of the microscopic size of the granulation area between host and graft) The cross sections at *C* one through healthy bone and the other through sclerotic bone show the difference in vascularization at these two levels The right (*A*) and wrong (*B*) ways of using the twin saw From Albee *Principles of Treatment of* Non Union of Fractures *Surg Gynec & Obst* Sept 1930 51 3 299 By courtesy of *Surgery Gynecology and Obstetrics*

Two longitudinal parallel saw cuts, about ⅜ to ½ an inch apart, are made in the fragment ends completely through the bone cortex to the marrow cavity with a motor twin circular saw (Fig 127) The distance between the saw cuts is arranged by adjusting the distance between the twin saws These cuts are made from two to three inches into the end of

each fragment from the line of fracture. While the fragments are held in good alignment, these cuts should always extend far enough from the line of fracture to reach well into the non-sclerosed active bone of each fragment. This distance is subject to considerable variation, depending upon the site of fracture and the extent of eburnation present. The distance the twin saws should be apart, *i.e.*, the width of the gutter for the graft, should vary according to the size of the marrow canal at the smallest diameter of the fractured bone involved in the cuts. With the small motor drill, holes are bored in the cortex on either side of the gutter to receive the smallest sized kangaroo tendon which will answer.

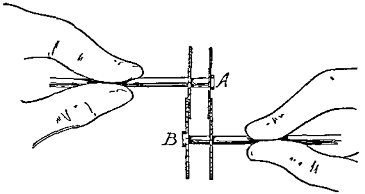


Fig 128.—The blades of the twin-saw, *A*, are adjusted to make the walls of the grooves in the bone fragments, into which the graft is to be fitted.

The blades of the twin-saw, *B*, are adjusted to remove the inlay graft from the tibia It will be noted that the saw-blades of *B* are set at a distance exceeding that of the saw-blades of *A* by just twice the thickness of the blade. By the adjustment of the saw-blades in this manner, a snug fit of the graft in its bed is assured. If the twin-saw is used unadjusted in the removal of the graft and in the formation of the bed, it would result in the graft being *twice the thickness of the saw-blade smaller than the width of the bed*, that amount of bone being lost in saw-dust. The above scheme is devised to avoid such an event.

These holes are placed near the line of fracture so as to fix the center of the insert.

The exact length of the desired inlay is obtained by measuring the gutter and transferring this measurement to the anterior surface of the tibia after its exposure. A flexible probe is usually satisfactory for this purpose, a right-angled bend marking the exact measurements. I have often used the carpenter's calipers. The wound and gutter are packed with hot saline compresses while the graft is being prepared. The graft yielding tibia is exposed by an incision over its crest. The overlying structures are retracted, and the size and shape of the graft are outlined in the periosteum by means of the scalpel with the probe measure and twin saw as a guide. With the twin saws adjusted to the same distance apart

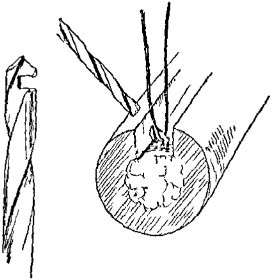


Fig 129 — Notched drill for threading drill hole in wall of gutter with kangaroo tendon From Albee *Orthopedic and Reconstruction Surgery* Saunders

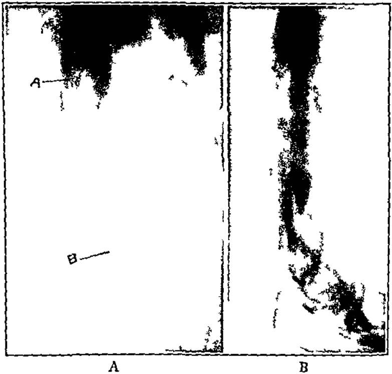


Fig 130 — *A* failure of intramedullary graft (*AB*) to stimulate union in the fracture of the humerus This *type of graft fails to secure proper blood supply*

B successful result after insertion of inlay graft by author's method. From Albee Principles of Treatment of Non Union of Fractures *Surg Gynec & Obst* Sept., 1930 51 3 302 *By courtesy of Surgery Gynecology and Obstetrics*

as when cutting out the gutter, plus the thickness of one saw blade (Fig. 128) bone cuts are made to the marrow cavity along the anteromesial aspect of the tibia. The saline drip is used by either of the means mentioned. With a small, motor driven saw, the graft is now cut at the ends

A and B C D E F

Fig 131—Failure of intramedullary graft and success of an inlay in the tibia. The failure of union after non-operative treatment is illustrated in *A*. The intramedullary graft is seen in *B* which shows also the extensive reaming out of the marrow and the destruction of it produced by manipulation of the graft in making it engage both fragments. Note shortness of graft indicated by arrows The author's inlay is shown 2 months after the operation (*C* and *D*) and 1 year after (*E* and *F*). From Albee, "Principles of Treatment of Non-Union of Fractures," *Surg, Gynec. & Obst*, Sept., 1930, 51, 3:301. By courtesy of *Surgery, Gynecology and Obstetrics*.

and dislodged by the osteotome. The graft, thus made of sufficient length to extend to the end of the gutter, will have generous contact with the vascular marrow substance and normal bone cortex on either side of the point of sclerosis and nonunion. In this way the marrow substance upon the graft has its best chance to be penetrated by host blood vessels and to act as a vessel conducting agent. An accurate fit is assured by the adjust-

ment of the twin saws which are used both in the shaping of the gutter and in the formation of the graft

Strands of kangaroo tendon passed through the drill holes previously made are raised on a long clamp from the bottom of the gutter, allowing the graft to be inserted beneath each of the four loops By tapping the author's bone set (of which the carpenter's nail set is the prototype) against different regions of the graft, with gentle blows of the mallet, the

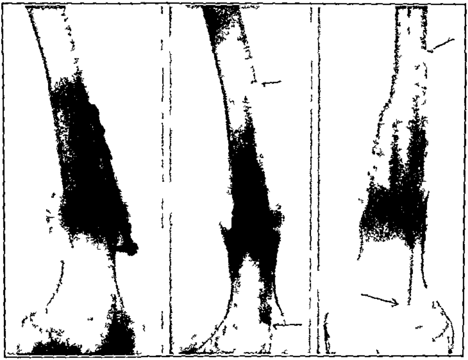
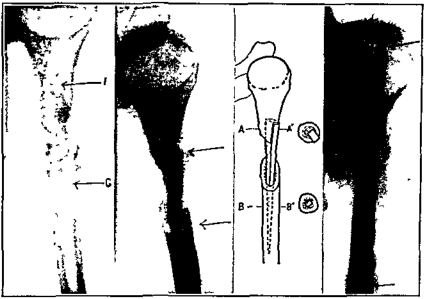


Fig 132 —*A*, failure of union resulting from use of Lane plate for fracture of shaft of femur
B lateral view Solid union 3 months after inlay graft (arrows) by author
C anteroposterior view

graft is firmly seated in its gutter The kangaroo tendon is then tied, care being taken that a secure knot is used, the last half of the knot is held by a ligature of chromic catgut No 1 tied at right angles to it to prevent any possibility of the knot untying under excessive stress In this respect, however, the conditions are most favorable in that two strands of the kangaroo come over the graft at each of the four points (Fig 129) The site of the fracture is covered with the periosteal flaps which were re flected to expose the bone to be removed This gives two layers of periosteum covering the transplanted fragment The overlying tissues and skin

are closed without drainage. It is most important that the tissues covering the graft be under no tension. No trouble results in this respect when the inlay is used, inasmuch as the diameter of the bone is not increased at the site of operation. All sutures should be absorbable and no larger than actually necessary (Fig. 130).

The soft parts are approximated with continuous suture of No. 1 chromic catgut; the skin is closed with continuous suture of No. 0 plain catgut. The line of suture is puddled with 3.5 per cent tincture of iodine



A B C D

Fig 133—*A*, failure of intramedullary graft (*IG*) to obtain union in fracture of the humerus

B, x-ray of case soon after insertion of graft according schema *C*.

C, schema of x-ray shown in *B* Note that union has occurred at *A*, whereas the lower end of the graft has failed to amalgamate with the shaft because of its intramedullary position. Also note that bone graft is inlaid at *A* so that it has favorable contact with the host bone

D, successful end result following long graft inlaid into both fragments by author.

splashed into the line of suture by means of blows of a completely saturated sponge on the end of an instrument.

Sliding Inlay Graft.—In most cases the graft material is obtained from the tibia. If, however, the bone involved is a large one such as the femur, tibia, or possibly, humerus in the adult, and the conditions are favorable for the use of the sliding graft, the twin saw enables a technic to be carried out whereby the graft is slid from one fragment to the other. This graft and the gutter in the receiving fragment may be formed completely by the twin saw, or the twin saw may be used merely as a marker and the single

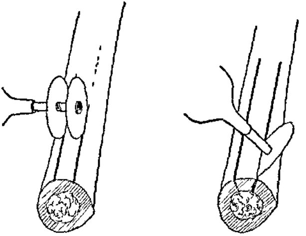


Fig 134 —Author's technic of obtaining the sliding or tibial graft with saw cuts converging to the marrow cavity This technic is used in fresh fractures of large bones From Albee *Bone Graft Surgery* Saunders

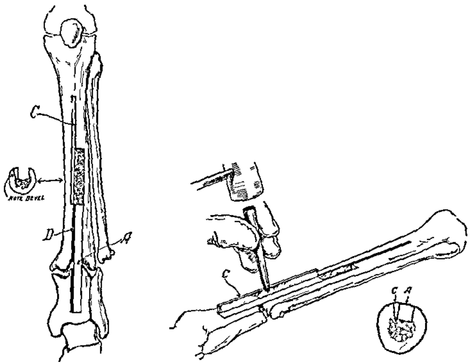


Fig 135 —Sliding graft in which I have evolved a method of holding the graft in place without the necessity of internal fixation sutures When grafts A and C are firmly tapped into place by means of a bone drift and mallet they will not come out.

saw used with converging saw cuts, so that, in the latter instance, the graft has a semi-wedge cross-section and its depression below the surface of the recipient bone will ensure a tighter fit (Fig. 134). Otherwise the technic is identical with that of ordinary inlay (Figs. 135 and 127).

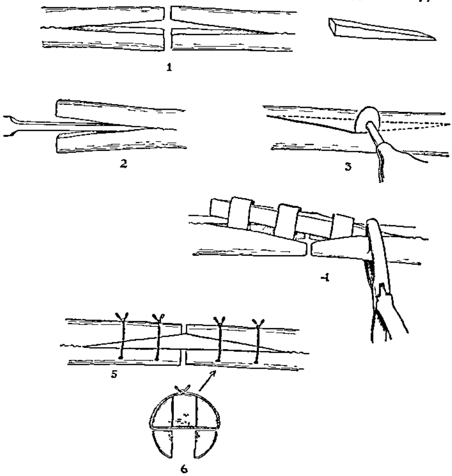


Fig. 136—Steps in the insertion of the double-wedge-end inlay. The wedges removed are shown, 1. The osteotome is being used to split the fragment beyond the recess when an oversize graft is necessary in smaller bones, 2. Removal of the graft from the tibia, 3. The U-shaped tin skids shown are used to facilitate the insertion of an oversize graft, the forceps causing the skids to separate and "spring" the bone as the graft is forced into position, 4 The position of the suture holes and final position of the suture are also shown, 5 and 6. From Albee, "Principles of the Treatment of Non-Union of Fractures," *Surg., Gynec. & Obst*, Sept, 1930, 51, 3 305. By courtesy of *Surgery, Gynecology and Obstetrics.*

Double-Wedge-End Graft (Fig. 136).—Whenever the bone fragments are small and conical in section, such as in the forearm in the adult, or when the bones are small or conical-ended in children, I have advised and employed for many years the double-wedge-end graft. In this instance the twin saw is not used at all. The wedge-shaped gutter is shaped

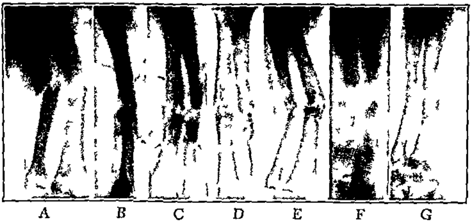


Fig 137—Successful use of the double wedge end inlay graft after the failure of seven operations The early condition is shown in *A* Failure of bone grafts is seen in *B* *C* *D* and *E* taken over a per od of 8 months The roentgenogram in *F* was taken 10 days after a later suturing operat on follow ng extensive removal of bone The result 6 months after the double wedge end inlay operation by the author is illustrated in *G* From Albee Princi ples of the Treatment of Non Union of Fractures *Surg Gynec & Obst* Sept. 1930 51, 3 303 By courtesy of *Surgery Gynecology and Obstetrics*

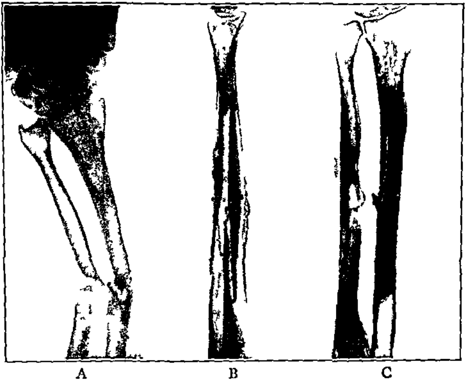


Fig 138—*A* unun ted fracture of both bones of the forearm
B x rays showing double wedge end graft shortly after operation
C, firm union six months following operat on.

by a single saw in a very similar manner to the gutter made by the twin saw. In this instance, however, the surgeon will have to use his judgment in determining just how large a wedge should be removed from either fragment. If the bones are especially small, the wedge-shaped cavity is enlarged by splitting the bone fragments longitudinally by means of a thin osteotome thrust into the apex of the wedge-shaped gutter distally

A B C

Fig 139—A, fracture of both bones of the forearm treated with Lane plates. B, extensive bone loss following infection caused by metal plates C, firm union after insertion of double-wedge-end graft by author.

to the point of nonunion. This causes the wedge-shaped gutter to spread so that it will receive a stronger graft of larger diameter at its center which determines its immobilizing strength. The drill holes are made precisely as in the ordinary inlay operation. A pattern of the graft is then mapped out upon the anteromesial surface of the tibia to measurements taken of the enlarged wedge-shaped gutters just made in the fragments. With a single saw a graft of the complete thickness of the cortex is removed. The technic of insertion is precisely the same as in the ordinary inlay, but the procedure is simplified by the use of tin clips. The size and strength

of the graft must be ample The sole object of the wedge shaped contour is to provide a means of inserting a larger and stronger graft (Figs 136, 137, 138, 139)

Sliver Onlay Graft (Fig 140) —Instead of the osteoperiosteal graft I use the sliver onlay graft which has mechanical continuity, contains all four bone layers, and responds to Wolff s law It can be taken from the side of the gutter where the large graft is obtained Being thin, it can adapt itself to the contours and pressures of surrounding parts It is a question whether, if the motor saw had existed in Ollier's day, he would not have used the sliver graft One end is made very sharp by means of the bone cutter, and this end is thrust under the periosteum or surrounding soft parts of one fracture fragment, while the other half of the graft comes in contact with the other fracture fragment

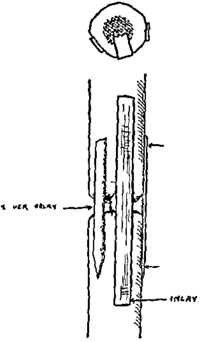


Fig 140—Sliver onlay grafts to augment inlay graft It contains all four bone layers and is thrust under the periosteum by sharpening one end

This type of graft is rarely used independently, but always for many years to supplement the immobilizing inlay graft (Figs 140 141)

Bolt Graft—The employment of the bolt graft is indicated in the lower leg or forearm where there are two long bones and a nonunion with or without loss of bone in one of them It has particular application in the tibia when there is such a contracted anemic scar at the point of nonunion that it is not even feasible to attempt to cover over an inlay graft It should be realized that the massive onlay graft is out of question in all cases where even the smallest increase in diameter of the operated bone may result in the impossibility of closing the skin The term ' bolt is chosen as referring to a graft with a cross section that is either oblong or rectangular In the case of nonunion of the tibia with loss of bone if pegs of sufficient strength were used from a tibial fragment, the strength of the fibula would be so diminished by the drill hole receiving the graft that it would be in great danger of fracture This danger is obviated by making multiple drill holes in both the tibial fragment and the fibula (see Fig 143), and the transference of these multiple drill holes into a mortise The small diameter of

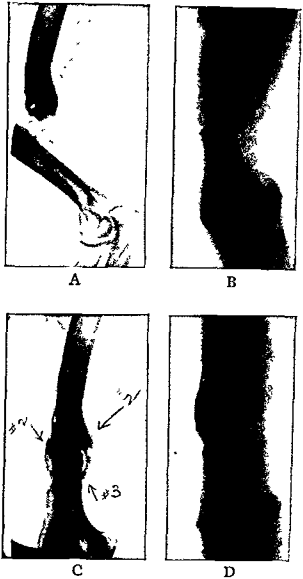


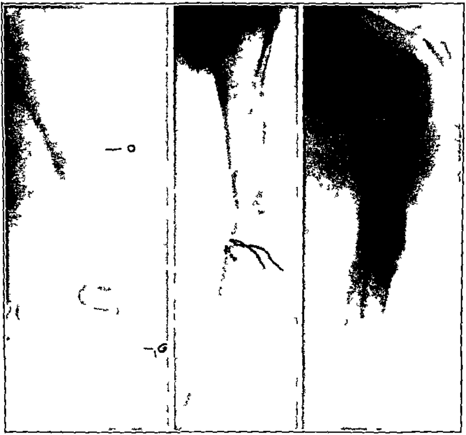
Fig 141.—*A*, ununited fracture of the humerus at the junction of the middle and lower thirds, with loss of bone substance. Fracture of three months' duration. On account of the unfavorable nature of the case, a tibial bone graft was recommended; the patient, however, refused to allow the graft to be removed from the tibia, and hence it was necessary to employ the author's sliding graft.

B, six weeks after operation at which a sliding inlay graft, 3 inches long, was dragged down from the upper into the lower fragment. Slivers of bone were obtained from the upper end of the groove and placed subperiosteally with one-half in contact with the upper and one-half in contact with the lower fragment. These sliver onlay grafts are shown clearly in position in the x-ray photograph.

C, x-ray ten weeks after operation, showing marked osteogenesis from the sliver onlay *grafts at the arrow points "2" and "3."*

D, four months after operation, showing complete consolidation. The active osteogenesis from the external sliver onlay grafts well shown in this case. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders.

this rectangular hole should be just sufficient to receive the full thickness of the cortex of the tibia at its anterior internal portion The thickness of this graft can be modified to a considerable degree by choosing the level of the tibia from which it is to be removed The bone plate



A B C

Fig 142 —A nonunion of fracture of the shaft of the humerus after several attempts to obtain union including wiring of the fracture and the use of onlay graft (OG)
B x ray after removal of onlay graft
C firm union after inlay bone graft operation

thus obtained can be modified as to its width to fulfill the conditions under which it is used (Fig 143)

Fixation by Bone Graft Dowel Pegs —Epiphyses, condyles, tubercles, trochanters tuberosities bone fragments, etc, may be very satisfactorily secured to the bone from which they have been fractured by the employment of bone graft dowel pegs, which are aseptically and speedily made by the author's dowel instrument (see pages 205 and 207) Their accu-

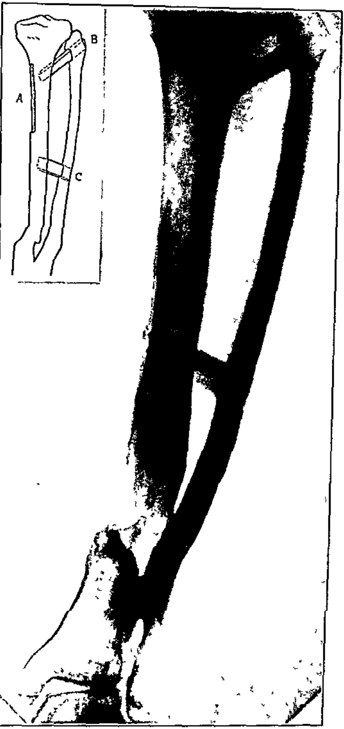


Fig 143—Method of bolting the tibia and fibula where excessive scar tissue at fracture site precluded the successful employment of inlay graft Bolt grafts at *B* and *C* (Inset) divert the body weight from tibia to fibula. Note hypertrophy of fibula at fracture.

rate fit is secured by employing the proper drill to make the hole into which they are driven (Figs 144, 146 147)

The material from which they are made can always be obtained from the crest or antero internal surface of the tibia if it cannot be more readily obtained in the original field Enough has already been said to emphasize the superiority of the bone graft pegs over metal nails or screws Screws of dead bone or ivory have a certain theoretical value in that they become absorbed as a rule, after a very long time From a practical standpoint however, they act precisely as foreign bodies in the bone and soft tissues, and may at any time have to be removed

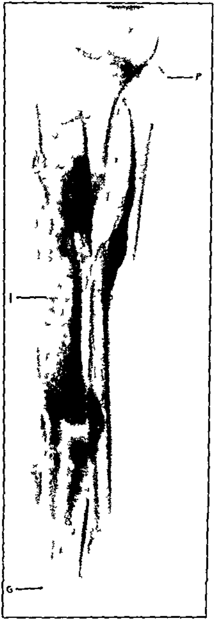


Fig 144—Inlay graft (*IG*) inserted for ununited fracture of tibia after many unsuccessful operations A bone graft peg (*P*) was inserted through the head of the fibula to fuse tibiofibula joint as well as to transmit part of the body weight through the fibula

Postoperative Treatment—In all cases the limb should be splinted in plaster of paris applied so as to immobilize the joint above and the joint below Too much emphasis cannot be laid on the importance of the careful application and moulding of the plaster It should be done either by the surgeon himself or by a well trained assistant on whose skill the surgeon can rely Proper immobilization after the operation is even more important than after the reduction of a fresh fracture In both cases laxity permits hinge movements at the site of fracture, but after the application of a bone graft it allows either rocking of the graft in its gutter or its displacement from the gutter, and results in fracture of the callus and disruption of the vascular bridges between graft and host

A suitable orthopedic table greatly facilitates the application of plaster or other dressing The cast should not be disturbed for eight weeks If nonabsorbable sutures have been

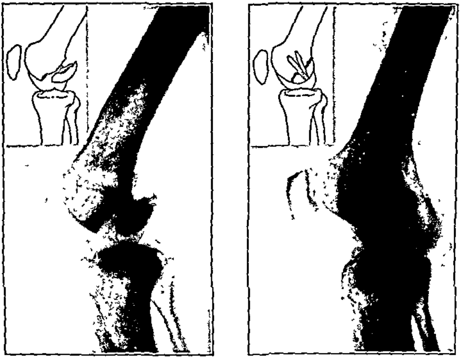
erroneously used, no harm is done by their actual removal or by cutting a window in the cast; the harm is done by removing the splint padding and dressing from over the line of suture. This disturbs the equality of splint pressure and ruins the immobilizing influence of the cast. A win-

A B C

Fig 145.—*A*, loss of 1/3 of the shaft of the tibia by osteomyelitis. Preliminary operation by author by means of a bone graft whereby the tibia and fibula were "bolted" together at *F*.
B, *second operation to restore tibia Bone graft* (*AB*) *was removed from the other leg* including 2/3 of the length of the shaft and used to span the defect.
C, showing hypertrophy of the bone graft in response to weight bearing. Restoration of function was complete.

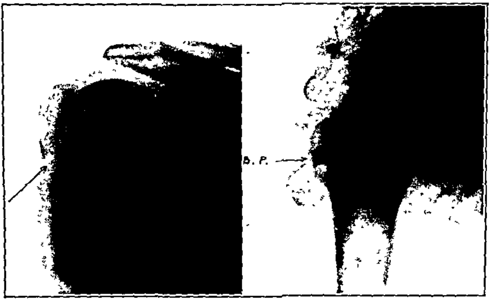
dow is liable to cause edema which produces increasing pressure and stagnation and may seriously disturb the nutrition of the healing bone.

When the cast is bivalved and removed, the limb is carefully and gently tested for consolidation. The region of fracture is then roentgenographed. If union is not complete, immobilization is continued with the bivalved



A B

Fig 146.—*A*, ununited fracture of femoral condyle of two years' duration.
B, bony union after coapting the fractured fragments with two bone graft pegs.



A B

Fig. 147.—*A*, ununited fracture of the greater tuberosity of the humerus containing insertion of supra-spinatus muscle.
B, one week following operation to replace avulsed fragment of bone by bone peg (*BP*). Function completely restored

cast. This is removed daily for massage not only of the area of operation but widely over the limb, the object being to stimulate the circulation and callus formation. If consolidation is not complete in a reasonable time, a brace may be so applied as to allow function without too much lateral stress on the point of nonunion. A surgeon is more efficient if he is able to design braces; he should, at least, be able to advise the maker and consult intelligently with him.

In many cases in which osteogenesis is slow, the critical period is during the stage of restoration of normal bony structure in the callus. As has

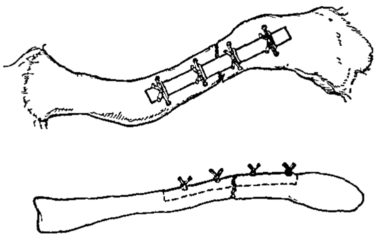


Fig 148.—Drawing of inlay graft inserted for an ununited fracture of the clavicle. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders.

been pointed out, the callus does not attain its full powers of resistance until the trabeculae have been rearranged in conformity with those of the host bone. In slow cases, this process may be delayed long after the callus has become hard and the limb apparently firm. It is during this period that physiotherapy is being used to stimulate enlargement of the graft and to restore full movement to joints after their restriction in casts; or the patient may be allowed to bear weight or carry his arm without support. It is obvious how carefully physiotherapy should be supervised and how gradually the patient should be allowed to bear weight, since weight bearing is one of the stresses which influence the trabecular reconstruction of the callus and the graft. Manual examination for consolidation should not be repeated too often. If the surgeon will keep in mind the various stages of repair, and not think of callus as a kind of glue that has set, he will be able to visualize the process of union and suit his postoperative cases to actualities. It is not always easy to steer a safe course since (1) full function should not be allowed until union is com-

A

B

C

Fig 149.—*A* preoperative roentgenogram of ununited fracture of the clavicle.
B double wedge end inlay graft
C, firm union after bone graft operation

plete and (2) the process of union is not complete until the new bone has been moulded by the stress of normal function.

In all cases the after-treatment must include much physiotherapy; the interval since the original fracture has been so long that joint stiffness and tendon adhesions are only overcome with difficulty. Baking and diathermy are followed by manual massage which is the most difficult, the most important, and the most exacting. The services of an expert (preferably a woman) are necessary. In thirty years, I have become more and

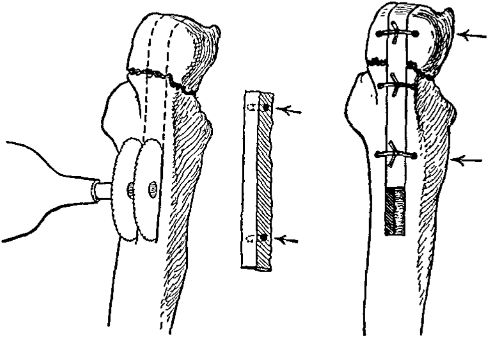


Fig 150.—*A*, technic of sliding inlay graft for fracture of the olecranon process. Arrows indicate drill holes in graft
B, the inlay graft is held firmly in place with kangaroo tendon. From Albee, *Bone Graft Surgery*, Saunders.

more convinced that only a woman can control a patient satisfactorily and so direct his mental reaction that he will not fear manipulations, but will surrender the limb without that sense of distrust which will engender muscle spasm and entirely defeat the objects of manipulation. Physiotherapy demands unusual qualities of mind as well as manual skill. There can be no formula since progression depends on the development of union, which only an experienced surgeon can gauge. The nature and extent of physiotherapeutic treatment must be determined, therefore, by the surgeon who maintains intimate acquaintance with the case and close coöper-

ation with the masseuse In most cases in which the graft fractures or breaks away from its attachment to the host bones, the fault lies in careless supervision of convalescent treatment or adherence to a routine in physiotherapy

Regional Modifications (For Ununited Fractures of the Hip, see page 130) —*Clavicle* —Treatment consists in freshening the bone surfaces, removing the pseudarthrosis, and approximating the fragments If the bone ends are attenuated and absorbed, a tibial bone graft inlayed across

A B

Fig 151 —Case of fracture of the olecranon before and after operation
A illustrates the wide separation of fragments due to action of the triceps muscle while *B* shows the close approximation of the fragments secured by the inlay bone graft and the rapid osteogenesis which has taken place From Albee, *Orthopedic and Reconstruction Surgery* Saunders

the fracture line or a double wedge end graft is utilized to stimulate osteogenesis (Figs 148, 149)

Berkheiser employs the author's technic and makes use of a combined inlay onlay bone graft from the tibia where a hiatus in the clavicle is present—and an autogenous osteoperiosteal onlay bone graft for delayed union

Olecranon —In ununited fractures of this process, the inlay graft, held in place by kangaroo tendon, can be easily applied on account of the super ficial location of the olecranon. A graft obtained from the tibia may be used, as conditions indicate, or, a peg graft may be used instead of the

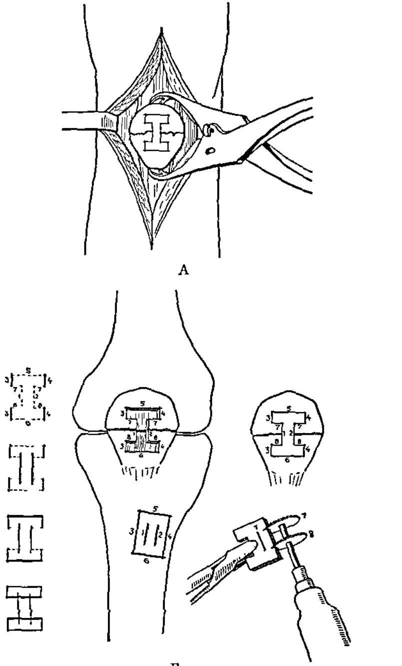


Fig 152.—A, author's bone tenaculum holding patellar fragments together during inlay graft operation using H-shaped bone transplant Mosaic inlay bone graft devised by author for ununited fractures of the patella. Graft is H-shaped and is designed to resist separation of the fragments

B, numbers indicate corresponding saw-cuts in patella and graft which were made in sequence. From Albee, *Orthopedic and Reconstruction Surgery,* Saunders.

inlay, as the surgeon may elect, but the inlay is preferred For this particular fracture, the peg should be made with a generous head, this can easily be done by not pushing the graft completely into the dowel cutter The forearm is flexed, and the insertion of the triceps into the olecranon split in equal halves down to the bone, the center of this end surface of the olecranon is then selected and a drill hole (using the proper sized drill) is bored completely through the olecranon fragment and into the long (shaft) fragment of the ulna for a distance of approximately 1¼ inches The drill is then withdrawn, and the peg (about ¼ inch in diameter) driven home (Figs 150, 151)

Fig 153—*A* ununited fracture of patella
B showing mosaic H shaped inlay graft as described in Fig 152*A*
C full function restored after solid union of fracture

Patella—In some cases muscle pull may interfere with union of the patella fragments however carefully the clots and fibrous material are cleaned from between them, or whatever suture material may be used to hold the fragments in close apposition Not infrequently, a failure of union or a refracture occurs, either immediately or remotely after operation, in spite of every precaution Fibrous union, with a varying degree of separation of the fragments and a proportional amount of disability in the extremity, is a frequent unfortunate result

To remedy either of these conditions, I use a capital I shaped inlay graft (or an H on its side) which bridges the fracture and holds the fragments firmly together in a most trustworthy manner

Albee Inlay Graft Technic—Ununited Fracture of Patella—For technic as in all bone graft operations on the extremities, a tourniquet is

applied to the upper portion of the thigh. The fracture fragments are approached by a curved linear incision, laying bare the patella and the upper portion of the antero-internal surface of the tibia from which the graft is to be obtained. This portion is chosen because the tibia is broad and of a plain surface at this point, and the cortex thin.

The fascial periosseous structures are dissected back intact in such a way that they may be approximated over the graft at the completion of the operation and serve as an immobilizing influence on the graft in its bed.

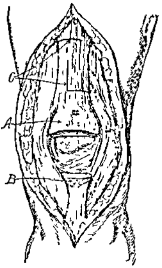


FIG. 154

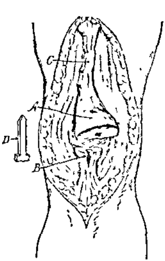


FIG. 155

FIG 154.—Technic used where patellar fragment (*B*) is too small for mosaic inlay graft. (See Fig 152*A*) Preliminary lengthening of quadriceps tendon by incision at *C*.

FIG 155.—Patellar fragments approximated by lengthening quadriceps tendon and slats made in upper fragments by multiple drill holes (*A*). Appropriate bone key (*D*) shaped to hold fragments together.

All fibrous tissue between the fragments is carefully removed. The fractured surfaces of the fragments are tilted forward and freshened with the small single motor saw and thin sharp osteotome. With the freshened surface of the patella fragments in close apposition, and held together with the author's bone tenaculum (Fig. 152) the outside measurements of a capital "H" one-half on anterior surface of each fragment with the shank of the "H" spanning the fracture-line, approximately (1¼" vertical x ¾" lateral) are roughly etched on the anterior surface of the patella and also on the tibia with the point of a scalpel. This form of mosaic inlay holds the patella fragments more firmly together than any other pattern. Then with the blades of the twin saw set about ⅜" apart, cuts 1 and 2 (or the vertical stem of the "H") are made in both

patella and tibia (Fig. 152). The blades are then readjusted to make cuts 3 and 4, and 5 and 6 in turn A complete rectangle is cut in the tibia; but in the graft bed in the patella, cuts 3 and 4 are merely marked with the twin saw as a caliper marker, and cuts made for the requisite distance in the upper and lower fragments with the small saw. The last cuts to be made in the graft bed are 7 and 8, after which the bone within the "H" is removed to a depth of ⅓" from the anterior patellar surface with a narrow thin sharp osteotome

The cuts corresponding to 7 and 8 in the patella are made in the tibial graft after the rectangular graft has been removed from the tibia; and in this instance, only extend to the "H"-stem cuts already made. These last cuts are made by feeding the graft, held by forceps, onto the twin saw edgewise while the motor is held by the assistant on the instrument table. This insures an absolute cabinet-maker's fit when placed in the graft bed in the patella.

It would be utterly impossible to cut a graft of this shape and get an accurate fit with the chisel and mallet, but the automatic machine tools make possible the most accurate inlay work, quickly executed

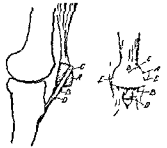


Fig 156—Bone graft key (*CD*) holding fractured patellar fragments in position

One inserts the inlay with its periosteal surface anterior and sutures the periosteal flaps of the patella over it with interrupted chromic catgut sutures. The rents in the capsule are then sutured with small kangaroo tendon as far as the sides of the patella To insure greater fixation, a figure-of-8 suture of medium sized kangaroo tendon is passed laterally to the anterior portion of the ligamentum patellae and quadriceps tendon, directly above and below the fractured bone, crossing in front of the transplant. The skin is closed by a continuous suture of No. 0 plain catgut.

The tourniquet is not removed until after the application of the cast, which is applied from the thigh to the foot, with the leg fully extended The cast is left on for five weeks Then it is bivalved, the leg lifted out, and an x-ray of the patella taken (Fig. 153).

As soon as union is firm, massage is given daily and partial weight bearing on crutches is allowed

When the separation of the fragments is so wide that the technic just described is impracticable, the quadriceps tendon is lengthened by plastic work, sufficient to permit approximation of the patellar fragments.

The fragments are then held in position by a tibial bone graft identical

with the one just described; or if the lower fragment or the upper fragment is extremely small, the technic illustrated in Figs. 154 to 157 or tibial bone graft screws may be used. This same technic may be used in place of the H-shaped graft in cases where the patellar fragments are not separated (Fig. 159).

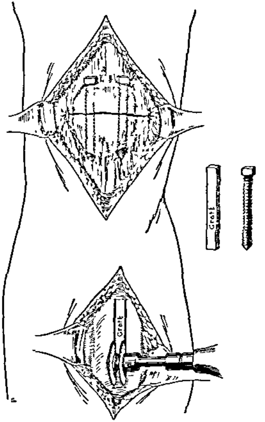


Fig 157—Alternate method of bone graft fixation of fractured patella. Two living bone screws are made in Albee bone mill and driven through screw holes made with corresponding size drill and tap (See page 216 of text.)

PEGGING THE TIBIAL TUBERCLE FOR AVULSION AND OSGOOD-SCHLATTER'S DISEASE

The tuberosity of the tibia may be firmly anchored to its bed following avulsion by means of the bone graft peg. A rectangular piece of bone is excised from the adjacent area of the tibia with the motor saw and the peg shaper of corresponding size to the drill is used to make the living bone peg which is then introduced into the drill hole (Fig. 158).

This same technic may be followed in treating epiphysitis of the tibial

tubercle (Osgood Schlatter's disease) The tendon is split longitudinally, retracted laterally, and the tibial diaphysis drilled to open up new sources of blood supply The bone pegs are then shaped and the tuberosity pegged to the diaphysis This method is useful in that an extended regimen of conservative therapy may be avoided The purpose of the operation is to

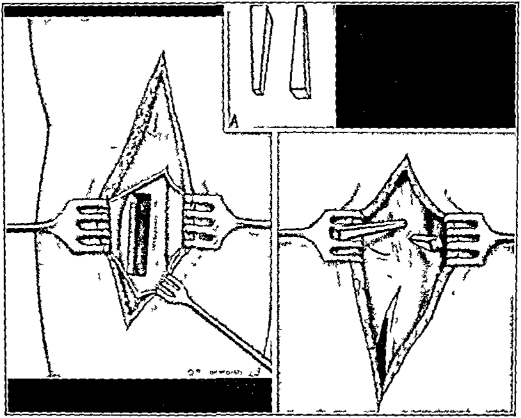


Fig 158 —Drawings show two pegs removed from a single site in the upper tibia through *the same incision used to expose the tibial tubercle The pegs are then placed one through* the tubercle and the other just above but in contact with the tubercle They should be driven through deeply so their bases are submerged beneath overlying soft tissues Drill holes are made at first but the square pegs being driven into the round holes crease the soft bone Due to the square and pyramidal shape they bind the tubercle area down firmly From Bosworth Lesions of the Tibial Tubercle and Their Treatment *Am J Surg.*, Feb 1939 43 2 527

bring about immediate fusion of the tubercle portion of the epiphysis to the diaphysis

This operation has been found necessary first, because of the difficulty in fixing the lower end of the tendon to the smooth surface of the patella, and second, because of the unusual tension exerted by the quadriceps muscle

Avulsion of the Quadriceps Tendon.—In avulsion of the quadriceps tendon from the top of the patella, one has the choice of two satisfactory methods: (1) after approximation of the quadriceps tendon to the patella, suture it with living fascia lata sutures placed through the tendon and converging drill holes in the top of the patella by means of Gallie or Gratz needles. The piece of fascia lata required is about one inch wide.

(2) In several instances, I have fastened the quadriceps tendon firmly to the top of the patella by means of a living bone graft screw or screws with large heads, obtained from the tibia of the same leg. The bone from which the screw is made is obtained with the twin saw and small cross-cut saw from the antero-internal surface of the tibia at its mid-portion. It is

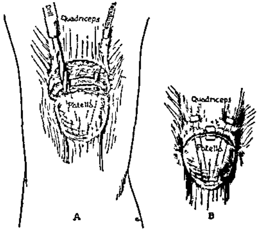


Fig. 159—Repair of avulsion of quadriceps tendon; showing (*A*) drill holes being made in patella with motor drill, and incision through the quadriceps with the tenatome. *B*, shows bone screws in position with the quadriceps tendon secured to the patella.

then shaped by the bone mill. The diameter of this screw is about ¼ inch and fits into the top drill hole made with the corresponding size drill (Fig. 159). The bone screws are introduced through oblique tunnels made through the quadriceps tendon with a tenatome.

Carpal Scaphoid.—Murray advocates the use of the bone graft in nonunion of the carpal scaphoid. He believes—"if the individual with nonunion of a fractured scaphoid is able to follow a sedentary occupation and avoid energetic use of the hand, he may have little discomfort; but if heavy labor, sport, or full range of movement of the wrist is important, the best prospects are offered by a bone graft." In our cases with nonunion, this form of treatment has yielded the best results. It is essential to have x-ray evidence that both fragments are viable and in appositions, and that there is no arthritis (Fig. 160).

Operative Technic—With the hand in full adduction, a curved incision is made along the radial surface of the wrist joint extending about 1¼ inches upward and downward from the radial facet of the scaphoid The ends of the incision are curved towards the posterior surface of the wrist and the convexity anteriorly should reach the tendon of the abductor pollicis longus The radial nerve and vessels and the abductor tendons of the thumb are retracted anteriorly, and the extensor pollicis longus tendon posteriorly This provides exposure of the tuberosity of the scaphoid A small transverse opening is made through the dorsal capsule of the wrist joint, exposing the dorsal surface of the radial facet of the scaphoid and on this surface the fracture line is apparent If the other bones of the carpus have not been disturbed by the injury the fragments of the scaphoid will not be displaced and in that case the fracture line is not disturbed by curetting, etc After clearing the most prominent area of the tuberosity,

A B

Fig 160—*A*, x ray taken 4 months after injury, showing non union of scaphoid *B*, x ray taken 4 months after bone graft showing solid union of fragments From Murray, "Bone Graft for Non Union of the Carpal Scaphoid *Brit J Surg* July, 1934 22, 85 67

a small nick is made in the bone at this point with rongeurs, in order to provide for countersinking of the graft and prevention of bone proliferation, which might interfere with abduction of the wrist joint

With a bit about 5/16 of an inch a hole is drilled, beginning at the nick in the tuberosity, through the proximal fragment, across the fracture-line, and into the distal fragment Great care is necessary to line the drill properly assisted by observations through the dorsal window, so that no cartilaginous surface is damaged The depth of the drill hole after the fracture-line is crossed, should be measured every few millimeters to prevent damage to the semilunar facet of the scaphoid by going too far

A suitable piece of cortical bone is removed from the tibia and shaped to fit snugly It is passed well through the medial fragment, taking care that the fragments are not separated, and is cut to leave no projection The dorsal ligament is repaired

The hand is supported in a circular plaster in a cock-up position for eight weeks. After this period all our cases in the general hospital had x-ray evidence of bony union,

and within a few months the fracture-line had disappeared. There was complete restoration of function, with a full range of movement in all directions without pain and with normal grip.[2]

Calcaneus.—The most satisfactory incision is one which passes along the outer side of the tendo Achillis down to the edge of the plantar skin, and then internally around the posterior part of the heel. The skin flap

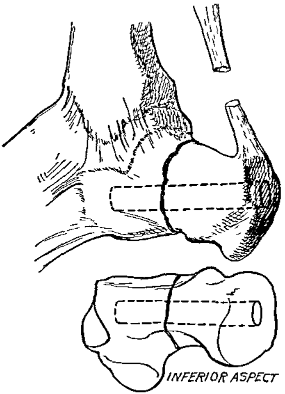


Fig 161.—Illustrates peg bone graft inserted for fracture of the os calcis. The tendo Achillis has been tenotomized to prevent posterior fragment being displaced upward. From Albee, *Bone Graft Surgery*, Saunders.

thus outlined is freed from the posterior end of the os calcis and retracted inward. Care should be taken to keep close to the bone in elevating this flap, so as not to interfere with its circulation.

With the posterior calcaneal fragment in good position, a hole about ⅜ inch in diameter is made longitudinally in the fragments with the author's motor drill (Fig. 161). The drill should be inserted in the center of the posterior end of the os calcis, driven through, and then disengaged from the motor and left *in situ*, while the peg is prepared. A strip of bone of sufficient size to be shaped into a dowel-peg is then removed from the

[2] Gordon Murray, *Brit J Surg.*, July, 1934, 22.85, 64.

crest of the tibia with the motor saw With the surgical lathe, held by an assistant on the edge of the instrument table, this strip of bone is pushed into the doweling instrument, which shapes it into a round peg that will exactly fit into the drill hole in the os calcis The drill is then withdrawn from the os calcis, the peg is inserted and driven home with blows of the mallet The end of the peg should be well countersunk into the end of the os calcis (using the special "bone set") so as not to cause pressure on the overlying skin and consequent necrosis and ulceration

Fractures of the avulsion type, resulting from muscle pull, may be treated in a similar way In this instance, the avulsed fragment is replaced and pegged securely in position by one or two small bone graft pegs, by a technic similar to that just described

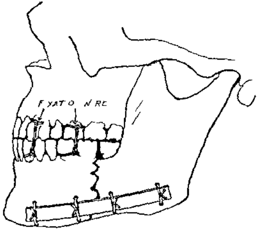
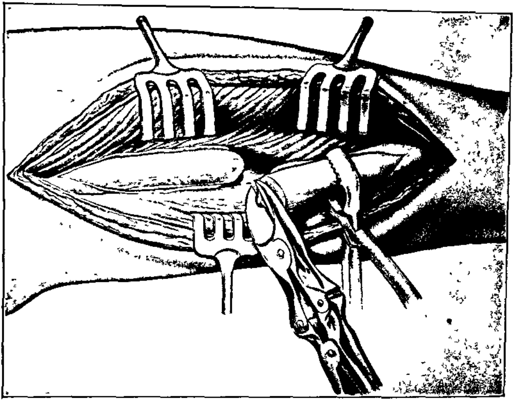


Fig 162 —Inlay graft for ununited fracture of mandible

The foot is immobilized in a plaster of paris dressing in moderate plantar flexion A pad of gauze is placed smoothly over the superior and posterior part of the heel, and as the plaster sets, it is moulded over this prominence with traction exerted downward The full arch of the foot is maintained by moulding the plaster well over the dorsal and plantar aspects of the foot After this treatment, the union in these cases is very prompt The plaster should be cut down and transformed into a bivalvular splint at the end of two weeks, when active motion of the foot and gentle massage may be allowed In the case of a fresh fracture, weight bearing may be allowed in four weeks' time If the case is one of mal union, this period of time should be somewhat lengthened in accordance with the individual requirements

Jaw —For simple ununited fracture without loss of bone substance, an inlay bone graft as illustrated in Fig 162 is the ideal agent for internal fixation



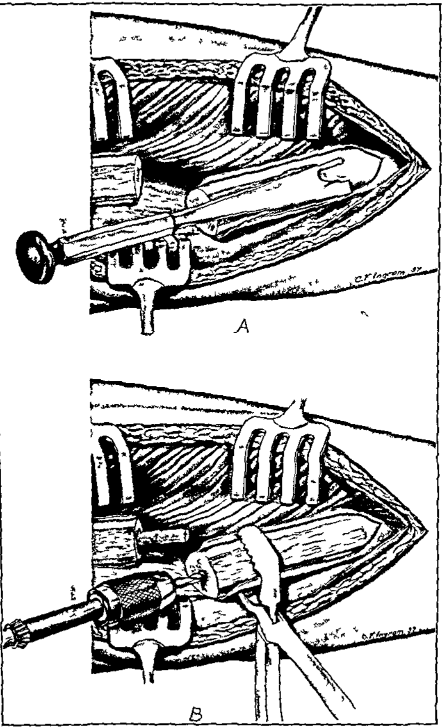
STEP I.

Fig 163—Campbell's massive onlay Graft technic for ununited fracture of the long bones. From Campbell, *Operative Orthopedics*, Mosley.

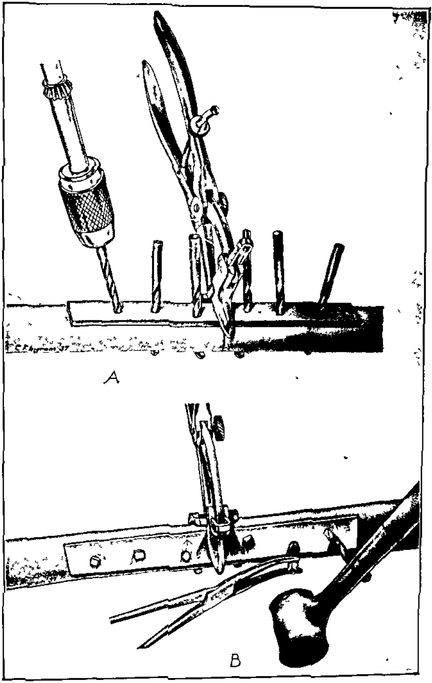
Step I.—Excision of eburnated bone from ends of fragments. Soft tissue attachments to bone preserved as far as possible

Step II (opposite).—*A*, "shavings" removed from small portion of circumference of shaft, forming flat surface three to four inches in length on each fragment

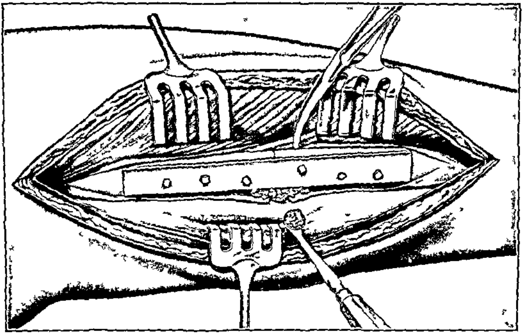
B, *each medulla is reamed out. Graft of endosteum placed in medullary canal as fracture* is reduced.



STEP II FIG. 163



STEP III, FIG. 163.



Step IV Fig 163

Step III (opposite) —*A* graft consists of cortex of tibia Note that drills are inserted in slightly different planes.

B drills removed and replaced by autogenous bone pegs of appropriate size

Step IV—Endosteum from inner side of graft and cancellous bone from tibial condyles packed about fracture site

ONLAY GRAFT

Henderson and Campbell have developed the use of the onlay graft. Operative technic is as follows:

An ample incision is made through the skin in order to expose each fragment, when possible, for 4 inches (10 cm.). Routine dissection is made to the site of fracture; all intervening scar and fibrous tissue is removed; the fragments are pared with chisel or motor-saw, and each medulla is reamed out until normal marrow tissue is reached. The fragments are rotated until normal relation has been restored. An incision is made through the periosteum of each fragment, for several inches, depending on the length and the anatomic location. The periosteum is stripped from one-half to three-fourths inch (1.3 to 1.9 cm.) from the circumference until there is a continuous flat surface, for 3 or 4 inches (7.5 to 10 cm.), when possible, on each fragment. A broad flat massive graft is taken from the tibia, which should be of sufficient length, breadth and dimensions to secure firm fixation. With a motor-saw, the graft is split longitudinally through the edge or small diameter into two parts, a strong outer plate consisting of dense bone or cortex, and an inner, the endosteum. A strip of endosteum is placed within the medulla, bridging the site of the fracture as reduction is made, normal marrow tissue rich in osteoblasts being thus restored. From the outer plate, or as a separate graft, a strip of dense bone is taken, from which six or eight autogenous bone nails of appropriate size are made. This is accomplished by the aid of a rotary file attached to the motor-saw and a metal gauge to measure dimensions. The strong outer plate is held to the flat surface of the fragments. Three or four drill holes are made through the graft and each fragment, into which the autogenous bone nails are driven. The remainder of the endosteum is broken into small particles and placed with the shavings about the site of fracture. By this method, solid fixation is attained so that when the operation is completed no motion is apparent. The transplantation of endosteum to the medulla and cavernous bone about the fracture is an excellent method to promote osteogenesis. (Fig. 163.)

The after-treatment consists in fixation by a plaster of paris cast which remains for a period of eight weeks; when this is removed a convalescent splint is applied, usually in the form of a leather corset to reproduce the cast. Joints are usually incorporated, so that active and passive motion may be carried out as soon as feasible. In the lower extremity, weight bearing is often gradually permitted by the aid of a Thomas ring, and apparatus is not discarded until the roentgenogram demonstrates that the callus is organized.[3]

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CHAPTER VI

BONE GRAFT SURGERY FOR REPLACEMENT OF BONE

RADICAL RESECTION OF BONE TUMORS WITH BONE GRAFT REPLACEMENT

The treatment of malignant growths of bone, especially primary bone sarcoma, was until recently desperately unsatisfactory. Most delayed amputations, preceded and followed by x-ray and radium therapy are able to secure lasting results in only a small number of cases. Metastases in the lungs may develop within a longer or shorter time after the amputation, quite often without involvement of the regional lymph nodes.

The uncertainty of the outcome in these radical and crippling operations, the severe psychic trauma that they usually represent for the patient, the difficulty of applying an artificial limb after exarticulation in the hip joint, all have led to less radical surgical procedures, applied earlier if possible, which, still aiming at eradication of the malignant tumor, are an attempt to save the extremity in its usefulness.

The experience gained in the successful restoration of bone loss following trauma or osteomyelitis has brought new light to bear on the hitherto discouraging problem of bone malignancy. Continued progress in the refinement of bone grafting technic, and concomitant improvement in the construction of the modern electrical bone mill have made available to the bone surgeon an effective weapon in the attack against the ravages of sarcoma. It is true that this method of procedure has necessitated doing the most extensive type of dissection—yet the results have provided ample justification for their undertaking. During the twenty-one years that I have been working on this problem, applying the latest developments in precision bone graft surgery, I have been gratified

to find that so many apparently doomed limbs were able to be salvaged At any rate, in doing resection, one has not "burned his bridges," but may still amputate if any signs of local recurrence are manifest

In the promiscuous use of amputation, the hazard of removing needlessly an extremity is considerable, and it is a catastrophe which should always be guarded against It is considered by many surgeons that the best method of dealing with very malignant and typical cases of osteogenic sarcoma is amputation, because if performed before metastases have occurred a cure may result Yet if this simple plan is pursued indiscriminately, many unnecessary and unsuccessful operations will be performed, and the best interests of the patient will not be served In cases seen early, prompt resection and restoration by bone graft should be strongly advised, because it promises a relatively favorable outcome Too much watchful waiting is to be discouraged in this type of case since it complicates, and may even make impossible the complete resection operation

Once operative treatment has been decided upon the surgeon must choose between a conservative surgical procedure and a radical one This question is almost as old as surgical therapy of malignant bone tumors itself It was Mikulicz who first emphasized the advantages of tumor excision over amputation and disarticulation There is little if any difference between these two methods of surgical treatment, radical and conservative, as far as metastases are concerned, and if the resection or excision of the tumor is well done, there is no reason why metastases should be more frequent than after amputation

In a group of 37 cases, there were only 3 local recurrences following resection and replacement—an incidence no higher than that following amputation However, it should be realized that when Mikulicz advocated excision there was no surgical method available for replacement of the resected bone Consequently, the limb, although markedly shorter and impaired in its usefulness was considered superior to prosthesis However, this discussion is no longer pertinent because of the ability of the modern bone surgeon to replace the resected area of bone without shortening by means of a bone graft transplanted usually from the tibia using automatic electrical instruments

In brief, the author s contentions are that curettage is inadequate and amputation in bone sarcoma is unnecessarily destructive The treatment of choice is early wide resection of the tumor with bone graft replacement A study of the author s results over a period of 21 years, leads to the conclusion that there is no increased danger of metastases in resection as compared with amputation Finally, it is believed that the readiness of

the patient to accept immediately the recommendation of the surgeon to resect as compared to his constant and everlasting resistance to amputation must be an important consideration in the decision in regard to therapy.

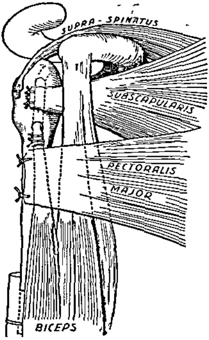

Fig. 164.—Diagram of method to restore the upper portion of the humerus and shoulder joint following resection for osteogenic sarcoma. The bone graft employed in this case was the upper *third of the fibula with its head articulating at the glenoid fossa.* Each muscle is fastened upon the fibular transplant in the place of its proper insertion by means of kangaroo tendon which was passed through drill holes made in the bone. See Fig. 171. From Albee, "Restoration of Shoulder *Function in cases of Loss of Head and* Upper Portion of Humerus," *Surg, Gynec & Obst*, Jan, 1921, 32, 1-4, 5. By courtesy of *Surgery, Gynecology* and Obstetrics.

Sarcoma of Shoulder Region.—*Illustrative Case.*—A woman, aged 25, complained of constant pain in the left shoulder, especially at night, and reported a slight loss of weight. The roentgenogram revealed a destructive lesion in the upper third of the shaft of the humerus with expansion into the soft tissues. The clinical and x-ray diagnosis of osteogenic sarcoma was made and later on confirmed and specified histologically as osteogenic sarcoma. Surgical removal was decided upon and performed.

The *operation consisted in the resection of* the head and 5 inches of the upper end of the shaft with replacement by a long piece of the fibula. More in detail, the operative procedure was as follows: The patient was placed on the fracture-orthopedic table and traction was applied to the left arm, which was kept in the same position throughout the entire operation. The tumor was exposed and a frozen section made. The soft parts were separated from the bone by blunt and sharp dissection, care being *taken to keep well outside the area of the new* growth. The shaft was completely severed by means of a Gigli saw, about 4½ inches from the upper extremity of the humerus, well below the tumor. After removal of the upper fragment, the upper end of the humeral shaft was prepared for the reception of the fibula transplant. The marrow cavity was slightly enlarged and by means of the twin saw, a groove was cut in the shaft for about one-half inch. The upper end of the fibula was then removed through *a posterior incision (because the fibula can be* exposed much more easily from behind and the peroneal nerve can be protected better). With the Gigli saw a piece of the fibula was removed so as to exceed the length of the removed humeral fragment for about 1 inch. The angular projections on the surface of the fibula shaft were roughly trimmed down with the motor saw, and the diameter of the shaft was thus made slightly smaller at the lower end so that it might be easily inserted into the humeral shaft. Then the fibula transplant was driven into the humerus until the head just engaged under the acromion process, *while traction was*

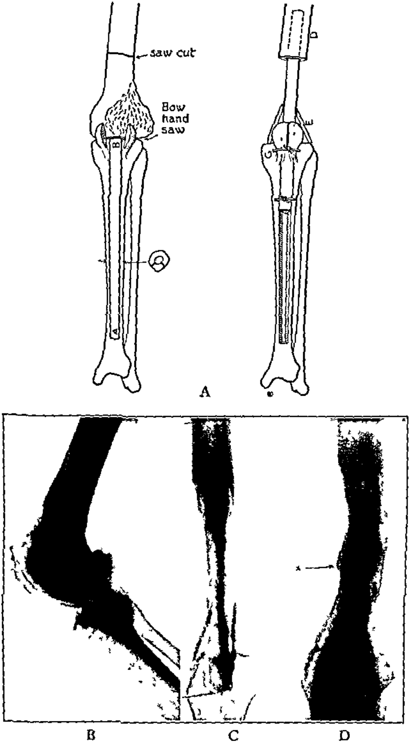

Fig 165—*A*, sliding bone graft used to replace defect in femur after resection of knee joint for osteogenic sarcoma Small sliver grafts form pyramid at the lower end for additional osteogenesis Upper end introduced into medullary cavity, lower end inlaid into tibia and reinforced by patella

B, illustrative case of osteogenic sarcoma of femur and patella

C, roentgenogram of extremity after operation using technic of 165 *A* Patella was excised in this case

D, x-ray two years after operation Note that diameter of bone graft at X is greater than

Fig. 166 A

Fig. 166 B

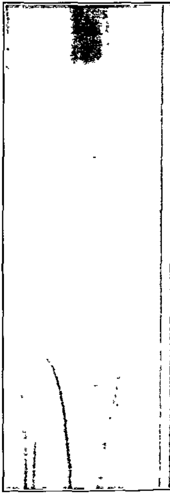

Fig. 166 C

Fig. 166 D

Fig. 166 E

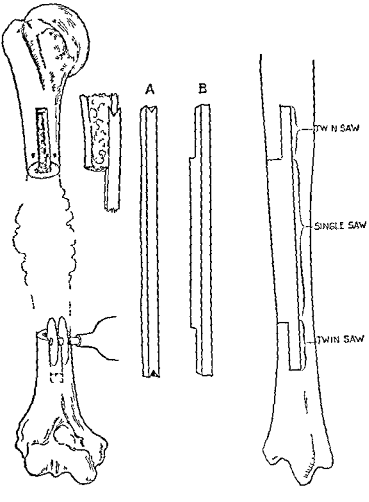

Fig 167—Inlay technic for the insertion of a tibial graft after the resection of a portion of the shaft of a long bone The prevention of the limb shortening may be accomplished in two ways either by a tongue and grooved joint as indicated at *A* or by shaping the graft so that it is larger in diameter where it spans the bone hiatus and has mechanical shoulders *at either end as indicated by* B *which is mapped out in the periosteum of the antero internal* surface of the tibia The latter technic is preferable The tibia is the source of the graft. (See Fig 168) From Albee *Orthopedic and Reconstruction Surgery* Saunders

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Fig 166 *Opposite*—*A* and *B* osteogenic sarcoma of the lower end of the femur
C and *D* *E* tumor resected and replaced by sliding tibial bone graft Note the marked hypertrophy of the graft From Albee "Treatment of Primary Malignant Changes of Bone by Radical Resection with Bone Graft Replacement *J Am M Ass* Nov., 1936 107 21 1693

exerted on the arm in order to restore the normal length of the upper arm. The upper end of the humerus was drilled in such a manner that graft and host were pierced completely. A kangaroo tendon was passed through the drill canal and tied securely.

The musculature was quite well preserved with the exception of the distal end of the pectoralis major, which had been resected for about one-half inch to keep away from the tumor. It was just possible to dissect out the various muscles, which were fastened each in the place of its normal insertion on the head and neck of the fibula by means of small kangaroo tendons passed through drill holes.

The arm was immobilized in a plaster cast for three months. There was solid bony union and the patient was encouraged to use the arm. She slipped and fell six months after operation. Roentgenograms revealed a fracture through the fibula graft. The arm was again immobilized and firm bony consolidation was present about ten weeks later. Under physical therapy, she regained so much use of the operated arm that she could play golf with it, play the piano and drive a car. She was last seen twenty-one years after operation. The shoulder was found somewhat lax and the left arm was considerably shorter than the right, but there was good function of the arm; the patient was even able to play the piano. Roentgenograms four years after operation showed that a part of the fibula had become resorbed at the site of insertion into the humerus, but there was sufficient periosteal bone formation around this area to prevent pseudarthrosis. Another picture, seven years after the operation, revealed good consolidation between graft and host. The head of the fibula was still well implanted below the acromion. There was no sign of local recurrence of the tumor (Figs. 164, 171).[1]

Knee Region (Graft Pyramid) (Fig. 165).—Under tourniquet, the knee joint is opened by a split patella incision, a motor-saw being used. The lower end of the femur is exposed. Great care has to be taken to keep away from the tumor, especially if there is already invasion of the surrounding soft tissues. With a Gigli saw the distal portion of the femur is resected and the upper joint surface of the tibia is freshened by removal of the entire joint cartilage. A strong sliding bone graft is taken from the crest of the tibia of sufficient length to prevent shortening. It is firmly anchored into the distal end of the femur and the proximal end of the tibia with the use of kangaroo tendons passed through drill holes. The sliding graft is reinforced by at least three sliver grafts, which are placed obliquely around so as to form a pyramidal structure with the base at the upper surface of the tibia. The two halves of the patella are also used for reinforcement. The soft tissues are then closed tightly and a hip spica cast used for immobilization (Figs. 165 and 169).

Shaft of Long Bones.—After resection of the tumor, the shaft is reconstructed by implanting a large tibial graft—as indicated in Figs. 167, 168. The prevention of limb shortening is accomplished by shaping the graft so that it is larger in diameter where it spans the bone hiatus and has mechanical shoulders at either end.

[1] *Surg., Gynec. & Obst.*, Jan, 1921, 1:19.

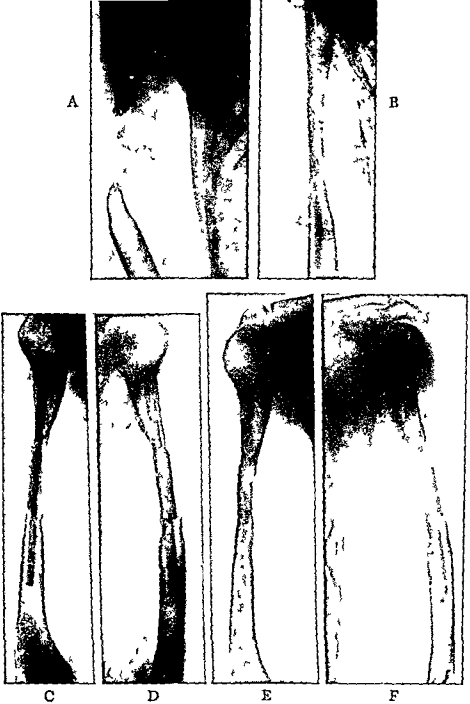
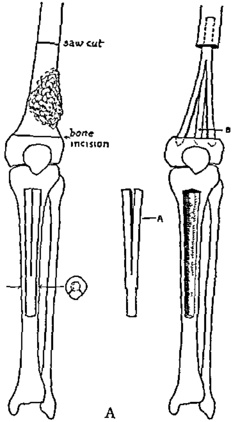


Fig 168.—*A*, loss of 4 inches of humerus from compound comminuted infected fracture Ends of bones are conical with thinned cortex with osteoporosis six months after the injury
B five weeks after implantation of tibial graft 9 inches long with small fragmented grafts (*bone seed*) *placed beside it at the humeral hiatus to hasten osteogenesis*
C, *D* three and four months after implantation of graft showing increase in diameter
E and *F*, six months after implantation of graft showing inlaid portions of graft adapting themselves to their environment *taking on the character of the humerus* while the graft at the hiatus is assuming the anatomical features (tubular shape marrow cavity etc) of its host bone *From* Albee *Orthopedic and Reconstruction Surgery* Saunders



A

B C D E

Fig. 169—*A*, resection of femur for sarcoma, leaving the condyles of the femur intact. Tibial bone graft (*A*) is crutch shaped Graft *B* provides additional support.

B, *osteogenic sarcoma of lower end of femur with epiphyseal cartilage uninvolved.*

C, three months after bone graft operation as shown in *A*. The shaft was resected, but the epiphyseal cartilage was left intact.

D, *four months after operation showing extensive callus deposition by bone graft.*

E, complete restoration of the shaft of the femur 2 years after operation with no evidence of local recurrence or metastases. Note diameter of bone exceeds normal.

Crutch Graft—When a malignant tumor of the femoral shaft is in close proximity but does not involve the epiphyseal cartilage in a growing child it is wise to salvage this structure in order to prevent future shortening of the limb The diseased portion of the diaphysis is resected leaving the epiphyseal cartilage and epiphysis intact After this is done a long tibial graft is mortised into each fragment of the bone across the gap (Fig 169) The graft is split longitudinally with a motor saw for ¾ of its length and the two parts spread into a Y or crutch shape Each of the prongs is then mortised into the inner and outer border of the epiphyseal cartilage while the stem of the Y is anchored to the shaft

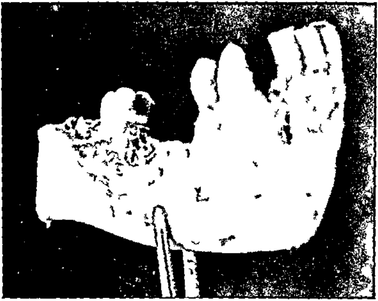


Fig 170—Portion of lower jaw removed for sarcoma Excised portion extended from symphysis in front nearly to the angle posteriorly For details of technic see page 277 and Figs 214 217 From Albee *Orthoped and Reconstruction Surgery* Saunders

One end of a second graft is then placed in the crotch of the graft and the other end mortised into the epiphysis The muscles are then drawn about and between the grafts with great care A double hip spica is applied

For technic of reconstruction of the mandible following resection for sarcoma see page 277 (Figs 167 170 214 218)

Bone Graft for Cyst of Upper End of Femur—A cyst of the upper end of the femur with degeneration and destruction of the head or head and neck of the femur presents a more formidable problem than when the disease is extra articular In the latter instance a tibial bone graft has been successfully employed to span the defect remaining after the

removal of the cyst. The graft is inlaid with one end in the lower fragment and the other end contacted into the acetabular cavity. If destruction of the acetabulum is sufficient to warrant immobilization, then the graft is mortised into the pelvis at a point above the acetabulum as well as inlaid into the upper end of the femur. The limb should be fixed in a long plaster spica in slight abduction for 10 or 12 weeks. In instances where the shaft of the femur has become markedly bowed because of the yielding of the weakened portion, I have corrected the deformity by a cuneiform osteotomy (by means of motor saw and osteotome) and have then inlaid a strong tibial graft through the cystic area. If the bow-

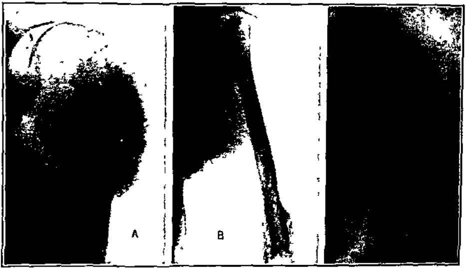


Fig 171.—Giant cell sarcoma with malignant tendencies The upper end of the humerus has been resected and replaced by fibular grafts. No signs of tumor recurrence. From Albee, "Treatment of Primary Malignant Changes of Bone by Radical Resection with Bone Graft Replacement," *J. Am. M. Ass.*, Nov., 1936, 107, 21:1694.

deformity is not too great to leave, further progression of the bending can be prevented by inlaying a tibial graft (same technic as when the bone is broken) through the weakened area. Mention should be made of Hall's work of radiation to the parathyroids before radical resection is considered. (See Figs. 127, 128, 134 and 135.)

Giant-Cell Tumor.—In giant-cell tumor the whole crux of the question is as to choice between various methods of treatment, each of which may lead to permanent cure. I believe it important to stress the word "may," for although Bloodgood has been very outspoken in his statement that giant-cell tumor is always benign, I have seen a number of cases the last few years in which this was not true. According to statistics, there is recurrence in about 20 per cent of all cases treated by curettage alone.

Among 222 cases of giant cell tumor in the surgical pathology laboratory of Johns Hopkins Hospital there were 31 recurrent cases following a primary curettement and many of these showed repeated recurrences despite surgical intervention In 3 additional cases metastases to the lung were responsible for the death of the patient Coley Stone Ewing Goforth Finch and Cleave have all reported cases of metastases from giant cell tumor

Kolodny points out that in exceptional cases a giant cell tumor may become a more malignant one as a result of repeated irritation from curettage and infection

In the treatment of giant-cell and benign tumors the pendulum is swinging toward primary operation and subsequent irradiation With the development of motor saw technic and precision in bone surgery in general resection and replacement by bone graft offers a chance of saving limbs safely far beyond what surgery formerly offered because it not only diminishes the hazard of the operation itself but allows wide resection without amputation Formerly one might just as well have taken off the leg but with the possibility of bone graft replacement this is no longer true (Fig 171)

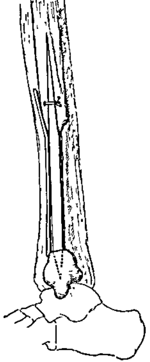
Speed and diminution of operative time and the avoidance of shock from the impact of mallet and chisel make possible wide resection They also make possible replacement of lost substance at the same operation as resection of the tumor (Fig 172) *For technic, see page 238*

Bone Graft Repair After Removal of Benign Giant Cell Tumor Involving Phalanges—Cole reports two cases of benign giant cell tumor of the phalanx The first of these involved the proximal phalanx of a toe and was cured five and one half years after amputation

The second involved the proximal phalanx of the thumb This patient was well sixteen months after the phalanx was resected and replaced by a bone graft from the tibia driven into the metacarpal head The result was a stiff but very serviceable thumb

RESTORATION OF BONE LOSS FOLLOWING TRAUMA AND OSTEOMYELITIS

In the task of restoring loss of bone substance and function in the wide variety of traumatisms encountered today the plastic surgeon is confronted with a correspondingly varied array of mechanical problems The recognition of the underlying biologic and physiologic significance of tissue growth and metabolism is a fundamental requirement in the successful treatment of these cases The surgical repair of bone and more



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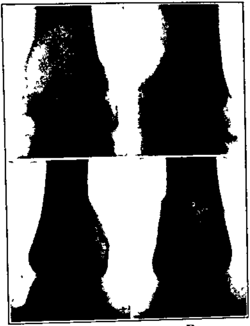

A B

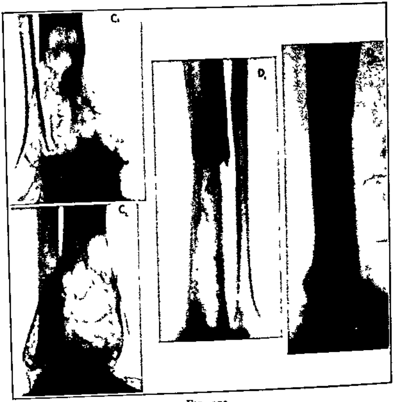

FIG. 172

particularly the use of the bone graft in cases of pseudarthrosis and osteomyelitis, is based not only on the ultimate establishment of adequate fixation of the bone fragments, but also on the attainment of a proper environment for the nourishment of the graft

Throughout his plastic work, both in civilian practice and army experience, the author has been greatly impressed with the striking influence exerted by mechanical stress on the growth and metabolism of bone In cases of loss of substance of long duration, in the radius, humerus or any long bone, the bone cortex has often become reduced to one fifth its normal thickness, in fact, almost to eggshell consistency, largely owing to removal of the stimulus of mechanical stress Such a condition is of course, in direct sequence to the general physiologic law of bone growth it is, in fact, a corollary of Wolff's law If bone, whose nourishment and blood supply have not been greatly impaired, should suffer so materially as a result of loss of the stimulus of mechanical stress, how much greater must be the effect of the same inhibitory influences on any free bone graft whose blood supply and nourishment are not yet established

A more suitable environment for successful bone growth is established by the cabinet maker's fit of the properly inserted inlay graft than by any other known technic At the same time, the biologic laws that pertain to the transplantation of all varieties of tissues are fulfilled since corresponding tissue layers are brought in apposition, thereby furnishing ideal conditions for the rapid and complete establishment of the blood supply Under such conditions, Wolff's law of bone growth is given favorable opportunity to exert its influence on bone proliferation and on the adequate adjustment of the bone architecture Moreover, by the inlay technic, the full influence of Roux's law of frictional irritation is ideally provided for, since extensive plane surfaces of the graft are brought into the close proximity with equally extensive plane surfaces of the host fragments

Technic —In every case operated upon, acute suppuration should have subsided and all infectious material and necrotic bone should have been removed and the skin completely healed for some weeks prior to operation, so that a clean field is assured

The fragment ends on either side of the hiatus are laid bare and the bed for the graft is prepared, care being exercised not to place the graft

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Fig 172 (opposite) —Upper left showing details of technic (*A*) giant cell tumor of the lower end of the tibia (*B*) *first curetted with implantation of sliver grafts* and *recurrence* (C_1 C_2) It was then resected and replaced by two cortical bone grafts (D D_1) implanted into the astragalus *There was no tumor recurrence* From Albee Treatment of Primary Malignant Changes of Bone by Radical Resection with Bone Graft Replacement" *J Am M Ass*, Nov 1936 107, 21 1693

in dense cicatricial tissue. The graft is inserted into the fragment ends by precisely the same technic as that employed in applying the inlay to ununited fractures, except that a shouldered or *tongue-and-groove joint* is used at the ends of the graft to prevent muscle-pull from shortening the limb by forcing the fragments together before union occurs (Figs. 167, 145).

The graft should always include the complete thickness of the tibial cortex, periosteum and endosteum, and some marrow substance. The other dimensions depend upon the bone whose place is taken or the mechanical strain to which it will be subjected. The muscle ends which have *been detached from the removed bone are attached to the graft in their* normal anatomical position by means of encircling sutures of kangaroo tendon. If the graft is inserted to take the place of the end of a bone, such as the upper end of the humerus or the femur, the upper end should be placed in the glenoid or acetabular cavity, and the capsule sutured around it. Extension is necessary at the shoulder to prevent the end of the graft from pushing through the capsule. If the ends of the fragments are small in diameter and spindle or conical in shape, it is best to split them with the *motor saw into equal portions for a distance of 1 to 2* inches. The corresponding end of the graft is fashioned into a long and slender wedge, its dimensions varying with the mechanical conditions encountered, and it is jammed into the cleft made in the end of its recipient fragment. The graft ends are secured to the host fragments by means of kangaroo tendon, either placed in drill holes or wrapped about the ends of the recipient bones and graft. The soft structures are drawn about the graft, with chromic No. 1 interlocking sutures and the wound is closed *with a continuous suture of No. 0 plain catgut.*

A carefully fitted plaster of paris dressing should be applied, including the joints on either side of the grafted bone. If there is no cause for its earlier removal, it should remain upon the limb for eight weeks, at the end of which time it should be replaced by a second plaster splint for one or two months, or until the roentgenograms and physical examination show that there has been a sufficient hypertrophy of the graft to be trusted without support.

Regional Technic: Shoulder.—Of all surgical conditions, few present a picture of greater helplessness than a shoulder with a dangling arm from which the upper portion of the humerus is missing. This may be the result of a severe crushing accident, of osteomyelitis, destruction by a projectile, operative removal of a tumor, or, in rare instances, congenital absence of bone.

The only solution of this problem of restoring skeletal support lies

in replacement of the missing bone by an autogenous bone graft The individual surgical problem varies with the condition of the shoulder musculature as well as the amount of bone lost, and on this basis, I classify the cases in two groups with respect to surgical treatment

Group 1, those in which the musculature is sufficiently preserved so that it is possible surgically to reconstruct a movable, functioning shoulder joint

Group 2, those in which the musculature has been so much damaged or destroyed as to render impossible any hope of restoring mobility at the shoulder joint itself Any function must be of a compensatory nature

Operative Technic for Group 1—The head and upper portion of the fibula are transplanted to replace the head and upper shaft of the humerus

Operative Technic for Group 2—This group includes cases of severe traumata, such as crushing accidents, or injuries from shrapnel or shell fragments in which there may be not only great comminution of bone or even its complete removal by passage of the projectile, but also destruction of the musculature to such an extent as to render impossible any hope of restoring the former shoulder joint motion These cases are the most difficult to repair, for here there is not only the problem of restoring the bone loss as far as possible, but of securing such posture of the arm as will allow compensatory function from the action of the scapulothoracic muscles It has been my custom in this type of case to restore the lost head and upper portion of the shaft of the humerus by a trusswork of tibial grafts stabilizing the upper arm and ankylosing the humerus to the scapula Following transplantation of the bone the arm is immobilized in plaster in an elevated anterior posture with the hand brought in front of the face so that later the scapulothoracic motion becomes compensatory for lost shoulder joint action

If there has been infection at any time, the patient is given daily treatments by deep massage prior to the plastic work upon the shoulder for the purpose of ascertaining whether any latent infection exists

Technic—With the patient in the dorsal position upon the author's fracture orthopedic table, the arm to be arthrodesed is first placed in an anterior elevated posture with the humerus rotated so that the hand comes in front of the face With the arm in this position in relation to the scapula, to utilize the powerful scapulothoracic muscles in place of the shoulder musculature which has been destroyed This position is maintained with 10 or 15 pounds of traction during the operation and also throughout the application of the plaster of paris shoulder spica which follows The importance of securing this posture of the upper extremity

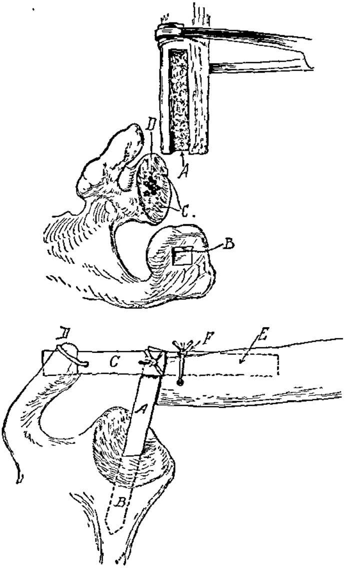


Fig 175.—*A*, diagrammatic drawing (superior view) showing groove, *A*, in humeral fragment, mortise, *B*, in acromion process; glenoid cavity denuded of cartilage, *C*; and holes drilled at *D*, preparatory to making the mortise in glenoid cavity.

B, diagrammatic drawing (anterior view) showing trusswork of tibial grafts in place and fixed with kangaroo tendon ligatures.

Graft *C* is inlaid into the groove prepared in the shaft of the humeral fragment, at *E*, and mortised into the acromion process, at *D*. This graft is slightly dented by the motor drill at *F*, and kangaroo tendon, passed through a drill hole at end of the humeral fragment, is fastened at this point in order to hold the graft more securely and prevent possible slipping A second kangaroo tendon ligature is made at *D*, passing through a drill hole in the graft and over the tip of the acromion process

Graft *A*, cut with one end wedge-shaped, is mortised into the glenoid body of the scapula, at *B*, and attached by kangaroo tendon to graft *C* at the point where the latter graft meets the end of the humeral fragment. From Albee, *Orthopedic and Reconstruction Surgery* Saunders.

and of maintaining it throughout the operation should be emphasized My fracture-orthopedic table makes this easy of accomplishment. By means of the table, the arm may be suspended anteriorly at right angles to the long axis of the trunk with as much traction applied as necessary, the body acting as the countertraction. During operation, the patient is held in the dorsal position upon this table; the exact posture of the arm varying in the two types of operation according to whether shoulder function is restored by the head and upper portion of the fibula, or through arthrodesis by means of a trusswork of bone grafts (Fig 173).

Having exposed the fields of operation, a longitudinal incision was made from the tip of the acromion process downward over the upper

174.—*In this case the scapulohumeral joint has been arthrodesed by a trusswork of bone grafts, but on account of the posture at which union took place the ability to bring the hand to the hair, face, or necktie has been restored through the compensatory motion between the scapula and the thorax*

Restoration of function by this means has been surprisingly gratifying owing to the action of the powerful muscles which control the scapula and thus, the arm to which it is united From Albee, "Restoration of Shoulder Function in Cases of Loss of Head and Upper Portion of Humerus," *Surg, Gynec & Obst*, Jan, 1921, 32, 1 15 By courtesy of *Surgery, Gynecology and Obstetrics*

end of the humeral fragment By sharp and blunt dissection, the end of the acromion process, the glenoid cavity and the upper end of the humeral fragment are thoroughly developed These are then made ready for the tibial grafts in the following manner: with the blades of the twin motor saw set ½ inch apart, the saw is introduced into the humeral fragment at its upper end and two parallel saw-cuts are made along the humeral shaft for a distance of 1¼ inches, and extending down into the marrow. A cross-cut made at the termination of the twin saw-cuts completes the formation of a rectangular portion which is removed to form a deep groove in the humeral shaft, as shown at *A* in the diagrammatic drawing (Fig. 173). In the acromion process, a mortise (designated *B*, in Fig. 173) is then made with its sides of the same dimensions as the width

of the humeral groove, just completed. The glenoid cavity (*Fig. 173 C*) is denuded of cartilage and drill holes are made at *D*, preparatory to forming a mortise.

Tibial Grafts.—About two-thirds of the antero-internal surface of the right tibia is then laid bare by a skin incision over the crest of the bone. A long graft is mapped out by the scalpel in the periosteum of the central portion of the antero-internal surface. This graft is ½ inch in width and about 8 inches long, which is of sufficient length to furnish

Fig. 175.—Progress of a case of gunshot wound with infection and loss of substance of the tibia. *A* shows the original infected wound *B*, *C*, and *D*, ineffective attempts at bone grafting, with material taken from the fibular graft is evident in *C*. *E* shows the result 7 months after the author's insertion of an inlay graft from the sound tibia It is now a year since the operation and the leg is functioning normally. From Albee, "Principles of the Treatment of Non-Union of Fracture," *Surg*, *Gynec. & Obst*, Sept., 1930, 51, 3:298. By courtesy of *Surgery, Gynecology and Obstetrics.*

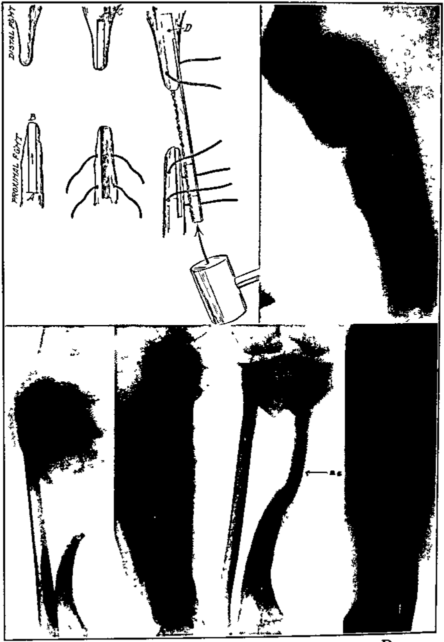
two grafts for the proposed trusswork in the right shoulder. The requisite length of the two grafts is first determined by means of flexible probes. The long graft is removed from the tibia by longitudinal cuts of a large single saw; a cross-cut is made to separate this graft into the two smaller grafts, one of which is cut with a wedge end. After removal of the grafts, the wound in the leg is closed in the usual manner by a continuous suture of the skin with No. 0 plain catgut, the suture-holes being "puddled" with 3½ per cent tincture of iodine and the excess immediately wiped away. A generous dressing of gauze and sterile cotton is applied with firm even compression.

Restoration of bone in the shoulder is then accomplished by means of a trusswork of the tibial grafts just removed (Fig. 173). One graft (*C*, Fig. 173) is inlaid into the groove already prepared in the humeral shaft and mortised into the acromion process. This is reinforced by the second graft (*A*, Fig 173) which has been cut with one end wedge-shaped, and is driven into the glenoid body of the scapula, and attached

Fig 176—*Use of a long inlay graft following marked destruction by osteomyelitis* The six inch gap in this is seen in *A* The inlay is illustrated in B, taken four months after the operation Subsequent fracture of the graft, seen in *C*, united when the limb was supported by a brace Not only reunion of the graft but marked enlargement of it is evident in *D* From Albee, "Principles of the Treatment of Nonunion of Fracture," *Surg, Gynec & Obst*, Sept, 1939, 51, 3 300 By courtesy of *Surgery, Gynecology and Obstetrics*

to the first graft at the point where it meets the end of the humeral fragment. The grafts are then fixed securely with kangaroo tendon ligatures. The fasciae and subcutaneous parts are then closed by a continuous locking stitch of No 1 chromic catgut. The skin closure is the same as that for the leg

Following operation, the arm is immobilized in the same anterior elevated posture with the hand brought before the face. A plaster of paris shoulder spica is applied from base of fingers extending up over the



A B C D

Fig 177.—Method of repairing extensive defect in tibia.

Top left, twin-saw cut from *A* to *B* Proximal fragment grooved, drilled, and kangaroo tendon sutures in place Twin-saw cut in distal fragment and upper end cut away by two drill holes, *C* Mallet driving graft into marrow cavity of upper fragment *D*, denotes portion of graft in marrow cavity.

Top right, failure of regeneration of tibia following destruction by osteomyelitis.

A, implantation of fibula into upper fragment.

B, restoration of bone defect by bone graft from tibial condyle to lower conical fragment as shown in *A*

C, six months after bone graft operation. Note continued increase of bone graft (*BG*).

D, anteroposterior view one year after operation

shoulder and thorax and down to the costal margins and the arm left undisturbed for 12 weeks At the end of that time, x ray examination reveals a firm union of the grafts, with considerable quantity of newly formed bone (Fig 174) Owing to the position in which the arm is immobilized, it is soon possible for the patient by the action of the powerful scapulothoracic muscles, to raise his right hand to hair, mouth, or neck tie, functions of which he was incapable before operation

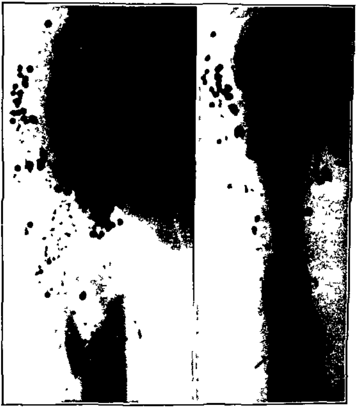
A B C D E

Fig 178—Case illustrating operative treatment of fractured graft. Osteomyelitis had resulted in considerable loss of substance with a hiatus between the fragments *A* The result 4 and 8 months *after the insertion of an inlay graft is evident in D Treatment* by *means* of sliding graft taken from original inlay and result are illustrated in *E* From Albee Principles of the Treatment of Nonunion of Fractures *Surg Gynec & Obst* Sept *1930, 51 3 300. By courtesy of Surgery Gynecology and Obstetrics*

In no part of the anatomy perhaps are the benefits to be derived from bone restoration more strikingly manifest than in replacing loss of bone at the shoulder Braces can accomplish very little in these cases of destruction of the head and upper end of the humerus, in which there is complete absence of skeletal support for several inches in the arm In a corresponding loss of substance in the upper radius, for example, the splint support of the ulna might be of considerable aid to the patient In the bony anatomy of the upper arm no splint support is provided for the

humerus; when loss of substance in the humerus includes the head, no type of brace devised can be of much aid in restoring to any satisfactory degree the lost shoulder joint function.

But by means of bone graft replacement of the lost portion of the humerus, restoration of shoulder joint motion and function *can* be accomplished. This is a plastic procedure which entails a thorough understand-



A B

Fig. 179—*A*, inlay graft in a case of gunshot wound with loss of substance. The nonunion, with little sign of callus, is seen in *A*. The result four months after the operation is illustrated in *B*. Callus can be seen about the graft. See Fig 167 for diagram of operation. From Albee, "Principles of the Treatment of Nonunion of Fractures," *Surg., Gynec. & Obst.*, Sept., 1930, 51, 3:300 By courtesy of *Surgery, Gynecology and Obstetrics.*

ing of the mechanics of the arm and shoulder and a technic based upon the physiological principles of tissue growth and healthy metabolism.

Long Bones.—Following osteomyelitis or a compound fracture with bone loss, extensive defects may be encountered in the long bones that require heroic efforts on the part of the surgeon doing reconstruction work. Bone graft surgery has made possible a considerable reduction in the incidence of amputation and the salvaging of apparently useless limbs.

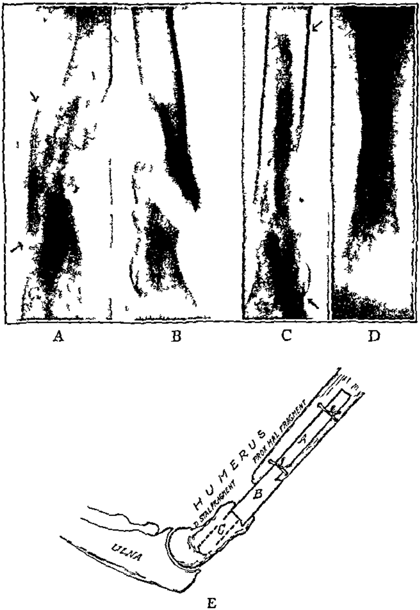


Fig 180—*A* fa lure of bone graft operation in unun ted fracture of the humerus by recrudescence of infect on

B follo v ng sequestrectomy

C author s first inlay destroyed at its central port on by infect on.

D the second and successful inlay into the remnants of the first

E d agram of techn c From Albee Principles of the Treatment of Nonun on of Fractures" *Surg Gynec & Obst* Sept., 1930 51 3 302 By courtesy of *Surgery Gynecology and Obstetrics*

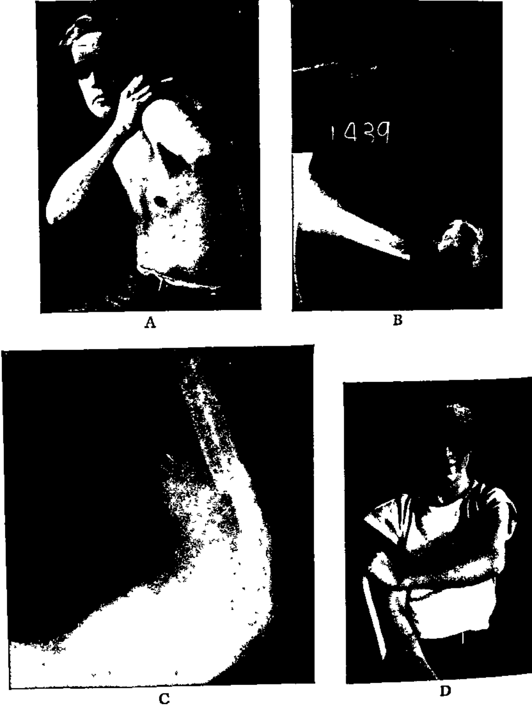


Fig. 181.—*A*, posture of left arm demonstrates extreme flail condition due to boneless state.

B, the roentgenogram shows loss of about 1½ inches of the shaft of the humerus.

C, the radiogram shows tibial bone graft of humerus firmly united in position ten weeks after operation.

D, ten weeks after operation. Note stability of arm from union of graft. Such a posture was impossible before operation, as shown by preceding figures. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders.

Illustrative Cases —*Tibia*—The patient was 29 years of age Nonunion of the tibia was the result of loss of bone substance following gunshot wound 5 years before Two attempts had been made by other surgeons to bridge the gap by bone grafts once by a sliding graft and once by a graft from the fibula The original infected wound with loss of substance is illustrated in Fig 175 The fate of the grafts is shown in *B* *C* and *D*

I used an inlay graft from the other tibia The result was excellent The roentgenogram shown in Fig 175 *E* was taken 7 months after the operation

The patient was a girl 8 years old Two years prior osteomyelitis had necessitated the removal of 6 inches of bone from the left tibia The condition when I saw her is illustrated in Fig 176 *A* The appearance of the graft 4 months after the inlay opera

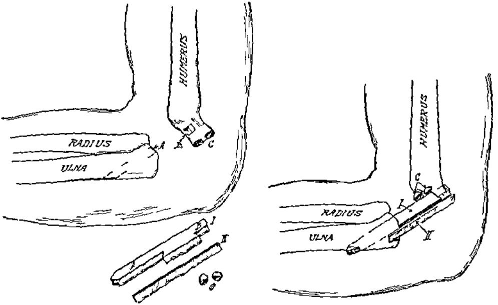


Fig 182—Arthrodesis of elbow and restoration of bone by means of graft in case of extensive loss of bone (gunshot) *A* and *B* holes chiseled following drill holes to receive Graft I *A* and *B* to be inserted into corresponding holes A and B *A* is sharply pointed to permit it being driven into *A* by mallet Graft II is a sliver graft

tion is shown in Fig 176 *B* A few months later the graft fractured as is shown in *C* The patient was given a brace and the graft reunited without trouble The roentgenogram (Fig 176 *D*) shows not only solid union but marked growth of bone in the graft It is now more than 8 years since the operation and the graft has given no further trouble

In this case a great deal of bone had been lost and was successfully replaced by a tibial graft The limit to the length of the graft is determined only by the length of the bone it is taken from (Fig 177) The case also demonstrates the probability that the fractured graft will reunite if adequate immobilization is provided If as occasionally happens it does not reunite even then a graft may be placed in the original graft (Fig 178)

Humerus—This case illustrated the use of the bone graft for loss of substance fol

lowing gunshot wound in an adult. The accident had occurred during a hunting expedition. There was much laceration of tissues and troublesome hemorrhage. Infection and sequestration occurred during the early course. The former was controlled by the Carrel-Dakin treatment and the wound healed after 9 months. Considerable bone had been lost and many shots were scattered through the soft tissues when I first saw the patient. Nonunion was present and there was little evidence of callus formation. (Fig. 175 *A*.) No attempt at surgical repair had been made and no fixation had been provided except by splinting.

I bridged the gap with an inlay bone graft from the patient's tibia. Figure 179 *B* shows

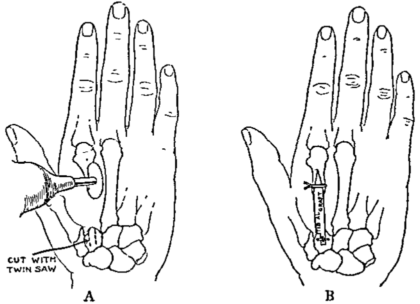


Fig 183.—*A*, illustrates technic in case of loss of central portion of the metacarpal of the index-finger from osteomyelitis, no periosteal regeneration after one year. Absent bone shaft restored by bone graft

B, illustrates completion of technic with tibial graft held in place with kangaroo tendon. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders.

the result 4 months later. Callus formation is evident about the graft. It is now 8 years since the operation and the graft is still solid. (See Figs. 168, 180, 182).[2]

Metatarsal and Metacarpal Bones.—The most satisfactory treatment is resection of the affected bone when destroyed by tuberculosis or osteomyelitis, with restoration of the part by a bone graft, especially in the adult.

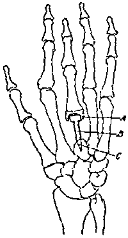
A straight incision is made in the dorsum of the hand or foot in line with the diseased bone. The extensor tendons are retracted. The periosteum is incised and elevated, together with the attached interossei muscles. The affected bone is divided with the small single motor-saw,

[2] *Surg., Gynec. & Obst.*, Sept., 1930, 51:289-320.

A

B

Fig 184—*A*, x ray showing loss of shaft of second metacarpal following osteomyelitis
B, after missing portion of metacarpal bone has been restored by author with a tibial graft See Fig 183 B for diagram of technic. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders



A

B

C

Fig 185—*A*, method of restoring shaft of metacarpal bone when destroyed by osteomyelitis with the purpose of preserving motion at the metacarpophalangeal joint
B, x ray showing defect
C, end result showing graft in position with excellent function obtained

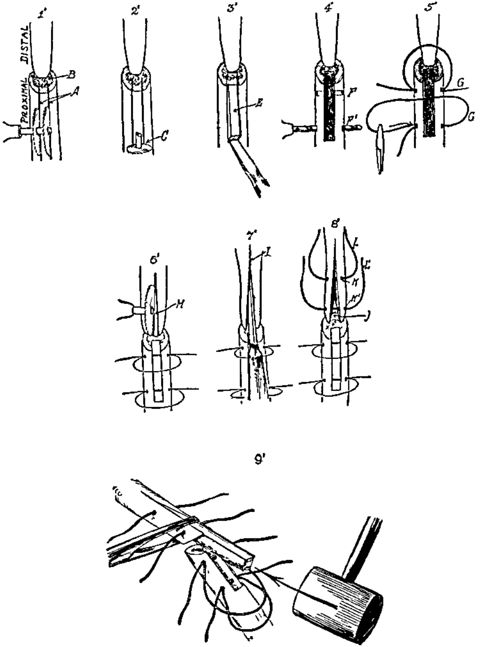


FIG. 186

10'

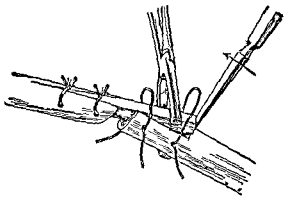


Fig 186—Series of Figs 1' to 9' demonstrates steps in author's technique used in Figs 183, and 184, cases where the end of the bone fragment (distal or upper fragment in this case) is *conical in shape, and too small in diameter to receive the usual inlay graft which is shown in the proximal or lower fragment in these drawings*

A wedge-shaped piece of cortex, *H*, is removed from the upper fragment A split at the end of wedge cavity may or may not be made by means of a thin osteotome, as shown at I If the fragment is small in diameter and osteoporotic, as is usual in these cases, the bone may be bent on both sides of the cavity in the region of I and the wedge cavity enlarged by driving a wedge ended graft of larger diameter into it, as demonstrated in steps Nos 9', 10' In this step, the wedge end of the graft is firmly immobilized in the distal or upper fragment by means of kangaroo tendon The other end of the graft is then forced into the proximal fragment by means of a strong clamp at the same time that the graft is being levered endwise by means of a narrow osteotome, the object being two fold, first, to restore as far as possible the length of the ulna, and secondly, *to bring end stress upon the graft as a stimulus to bone growth These drawings are made with distal fragment of ulna upper-most because of position of arm during operation* From Albee *Orthopedic and Reconstruction Surgery*, Saunders

osteotome or bone cutter beyond either end of the diseased area, but an attempt should be made to save the head of the bone and not to encroach on the epiphyseal cartilage or enter the joint.

In the case of the first metacarpal bone, the incision is made along the radial side of the extensor brevis pollicis and the periosteum incised between the origin of the abductor brevis pollicis and the abductor indicis

For the Phalanges.—Lateral incisions are employed between the extensor tendon and the digital vessels and nerves The periosteum is elevated and the bone resected, an attempt being made here as with the metacarpals and metatarsals, to save the head of the bone and the epiphyseal cartilage and to avoid the joint, when inserting the graft.

In the case of the first phalanx of the great toe, a single lateral incision is used to the inner side of the extensor tendon.

The bone defect is replaced by a graft taken from the crest of the tibia of the same patient (Fig 183). If phalangeal or metacarpal stumps are not too short the graft is mortised or inlaid into them. Strong traction

should be applied to the distal end of the finger or toe while the graft is being inserted tightly into place. A snugly fitting plaster splint should be applied to the finger and hand, or toe and foot, and allowed to remain in place for eight to twelve weeks. The resistance of cortical bone graft to tuberculous infections and to attenuated infections of other varieties has been repeatedly proved by the author. As a rule, the functional and cosmetic results are excellent (Figs. 184-185).

Ulna: see Fig. 186.

Radius: see Figs. 10, 137, 138.

Mandible: see page 284.

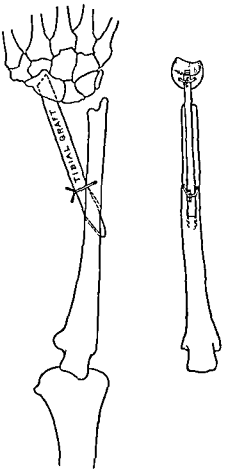


Fig 187—Author's technic for congenital absence of the radius The tibial graft is mortised into the ulna and scaphoid bones From Albee, *Orthopedic and Reconstruction Surgery,* Saunders. (See Fig 188)

CONGENITAL ABSENCE OF BONE

Radius.—This anomaly is rare. It *is more often unilateral than bilateral,* and generally right-sided. There is *usually complete absence of the bone.* The forearm is shortened and atrophied, and the ulna usually has a concavity toward the radial side. The hand is in radiopalmar deviation and is small and atrophied. One or more metacarpal bones are often absent, with or without absence of the corresponding phalanges. The thumb is rudimentary or absent and without a metacarpal bone. Other congenital anomalies frequently co-exist. Individuals afflicted with this congenital deformity usually exhibit low resistance and die young or are stillborn.

Treatment.—The only treatment of any avail is restoration of the defect by bone graft, the material for which is obtained preferably from the patient's tibia. The two ends of the graft should be fashioned either into a wedge or peg-shape, and inserted in properly prepared orifices in the carpus below and the shaft of the ulna above (Fig. 187). Although it is usually preferable to mortise the graft into the

shaft of the ulna, the upper end of the graft may be placed between the muscle planes of the forearm in the region where the upper end of the radius should be situated.

In one case, because of congenital absence of the carpus, the graft was mortised into the first metacarpal at the distal end The proximal end was placed between the muscles on the radial side of the forearm instead of being mortised into the ulna At the time of its insertion, the graft

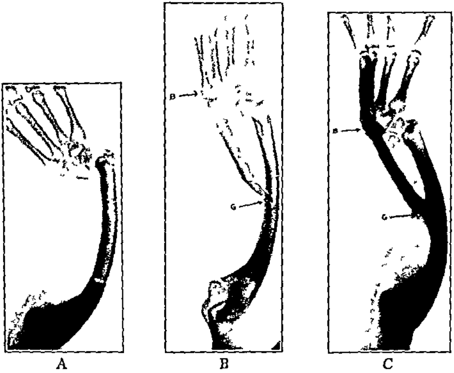


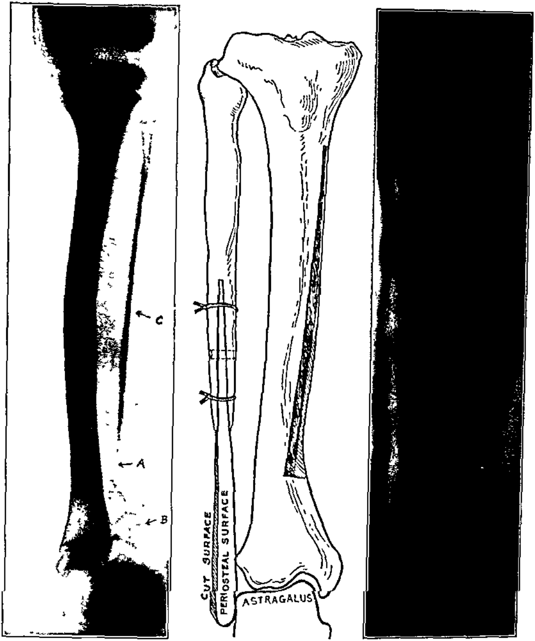
Fig 188—*A*, deformity of hand resulting from congenital absence of the radius Note subluxation of the ulna at the wrist

B, following author's operation to restore the radius by bone graft (*BG*), extending from the carpal bones below to the shaft of the ulna above (See Fig 187)

C, successful result with marked stability imparted to the hand by the bone graft

was under considerable lateral tension because of the marked tendency of the hand to seek an angular posture with the forearm toward the radial side.

As a theoretical consideration, at least, it would seem that placing the upper end of the graft between the muscle planes affords a certain advantage as it will allow the graft to be pulled down slightly during growth, thus taking advantage of epiphyseal growth at both ends of the ulna, and minimizing distortion during growth, which occasionally occurs,



A B C

Fig 189.—*A*, partial congenital absence of the fibula with marked valgus position of the foot because of the lack of external malleolus support. Fig *B*, shows the scheme of operation, and Fig. *C*, the tibial graft *AB* in place. From Albee, *Bone Graft Surgery*, Saunders.

owing to the epiphysis at the carpus being pushed out. On the other hand, stability may be slightly jeopardized by this procedure, and because of this latter consideration, it is not adopted routinely (Fig. 188).

In one of our early cases reported in *Orthopedic and Reconstruction Surgery,* the first graft was not mortised at either end, but merely placed between the muscle planes, in contact with the scaphoid at the distal end This graft proved unsatisfactory because it did not afford sufficient mechanical support. A second graft was inserted five months later, and firmly mortised at each end by the author's inlay technic. This united firmly and afforded excellent support to the wrist. The x-rays taken six months after operation showed increase in strength and dimensions of the graft, as in the case described

Fibula.—Freund believes that a diagnosis of complete absence of the fibula should not be made before the fifth year of life He bases this contention on the fact that although roentgen examination may show total absence of the fibula at birth, yet re-examination after several years may reveal a hypoplastic fibula. His classification includes three groups: complete absence, partial absence, or hypoplasia of the fibula.

Fig 190—Congenital absence of the right leg The conical stump contains an underdeveloped tibia, shown in Fig 192, as well as small underdeveloped foot bones It was necessary in any event to remove this conical projection in order to furnish a suitable stump for an artificial limb

The fibula is entirely absent from the left leg and the foot, and on account of lack of support of the external malleolus the foot is so distorted that the internal malleolus rests on the floor The deformity of the foot was corrected by lengthening the tendons and severing the soft tissues on the outer side of the ankle, and the underdeveloped tibia of the amputated stump of the right leg served as an ideal graft according to the technic illustrated in Fig 193 From Albee, *Orthopedic and Reconstruction Surgery,* Saunders

Practically the problem resolves itself into a consideration of the mechanics of the ankle joint. Without the external malleolus the mortise is incomplete and operative measures must be directed to its reconstruction.

When the lower end only of the fibula is absent, a tibial graft may be shaped to provide an external malleolus as illustrated in Fig 189. However, with complete absence of the fibula, the upper

pole of the tibial graft must be anchored to the tibia. The following case illustrates a *method of approach:*

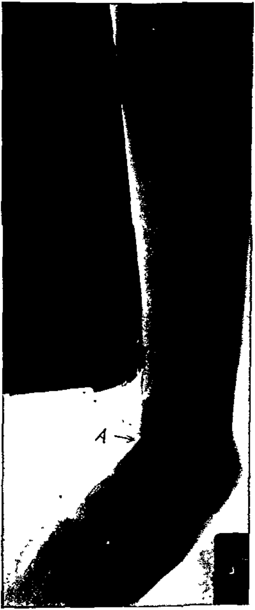
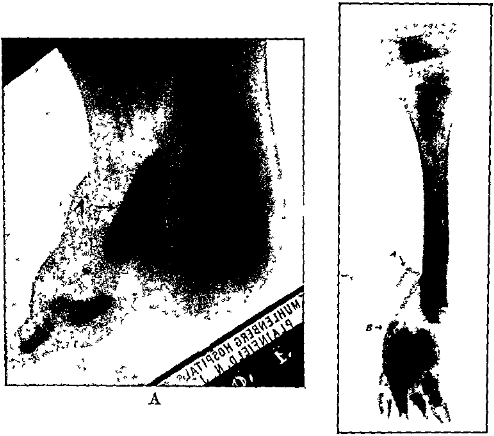


Fig. 191.—Anteroposterior roentgenogram of same case as Fig. 190. The absence of the fibula and the displacement of the os calcis, *A*, and the astragalus is shown. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders

A child was born with the foot and lower third of the left leg absent. A conical stump containing an undeveloped tibia projected backward

from the posterior aspect of the thigh (Fig. 190). The right fibula was entirely absent, and on this account the foot on this limb had become displaced from weight bearing and muscle-pull to a pronated position, with its plantar surface facing directly outward and firmly contractured. The lower end of the internal malleolus had become the chief weight-bearing portion of the foot.



A B

Fig 192.—*A*, roentgenogram of stump of same case as Fig 190 It shows the underdeveloped *tibia which was used as a graft to restore the external malleolus of the child's left leg, as* shown in *B* From Albee, *Orthopedic and Reconstruction Surgery*, Saunders (See Fig 193)

The problem presented in this case (a child 5 years of age) was, if possible, to correct the distorted foot and provide a means of maintaining the correction without, at the same time, interfering seriously with its function by the loss of ankle motion The most feasible method was to supply the missing support of the lower end of the fibula. This is best done by restoring the bony anatomy of the part, which can be accomplished in no other way than by resorting to the use of the bone graft.

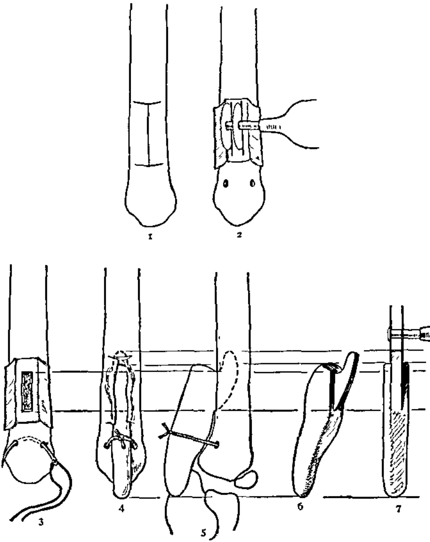


Fig. 193.—Improvising an external malleolus.

1, periosteal incisions. 2, formation of gutter to the medullary cavity in the outer aspect of the lower end of the tibia with the motor twin saws, after turning back the periosteal flaps The drill holes for fixation sutures. 3, the gutter formed and a curved cervix needle threaded with strong kangaroo tendon inserted in the drilled holes. 4, the graft secured in position, lateral view. 5, the graft secured in position, anteroposterior view, 6 and 7, with the motor twin saws adjusted the same distance apart as when forming the gutter in 2, the hook is accurately shaped on the graft. This hook is important in that it prevents the upward displacement of the graft by muscle pull and weight bearing From Albee, *Orthopedic and Reconstruction Surgery*, Saunders.

In this instance, excellent material for this purpose was easily obtained from the conical stump of the left leg (Figs 191, 192) The technic of the procedure was as follows

A curved incision, so placed that its closure would not bring the skin sutures over the contemplated site of the graft was made over the outer and lower end of the tibia and the outer surface of the os calcis The position of the foot was corrected after extensive division of fascia, ligaments and contracted tissue The outer aspect of the lower end of the

Fig 194—Photograph of the same case as Fig 190 four months after operation Shows correction of the distortion of the left foot also the well formed stump of the right leg The arrow indicates a Wolff's skin graft (about 2¼ in by 1½ in) which had been obtained from the trimming of the stump of the right leg

It was found after the correction of the valgus deformity of the foot and the insertion of the bone graft that there was not enough skin to close in the external side of the leg and a skin graft was used to fill in the uncovered area Both skin and bone grafts healed in by primary union From Albee *Orthopedic and Reconstruction Surgery* Saunders.

tibia was exposed and the periosteum was split longitudinally from a point about ½ inch above the epiphyseal cartilage extending upward for about 1½ inches These periosteal flaps were retracted laterally and, with the twin saw adjusted about ¼ to ⅜ inch apart, cuts were made in the long axis of this bone from ½ inch above the epiphyseal cartilage upward for about 1 inch (Fig 193) The strip of bone between these saw cuts was then removed with the help of the author's small circular motor saw and a sharp narrow osteotome Caliper measurements were taken and the size and shape of the desired graft planned The lower end

of the tibia near its outer portion was drilled for a kangaroo fixation suture, anteroposteriorly about ¼ inch above its epiphyseal cartilage.

The wound was packed with a hot saline compress, and the conical stump of the left leg containing the undeveloped tibia was removed

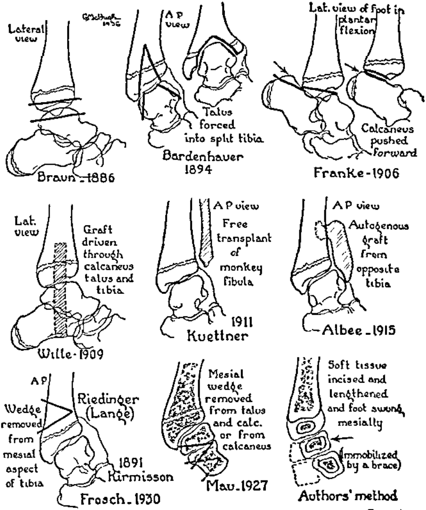


Fig 195—Methods advocated for stabilization and correction of equino-valgus deformity resulting from congenital absence of the fibula. Harmon and Fahey, "The Syndrome of Congenital Absence of the Fibula," *Surg., Gynec. & Obst.*, May, 1937, 64, 5:884. By courtesy of *Surgery, Gynecology and Obstetrics.*

through an elliptical incision, so planned that a satisfactory artificial limb-bearing stump would be produced. This wound in the left leg was closed by a continuous catgut suture and sterile dressings were applied. The conical stump of the leg which had been removed was then freed of its undeveloped tibial segment, which was moulded with motor tools

to simulate the contour of the lower end of the fibula With the twin motor saw adjusted for making the gutter in the tibia cuts were made into the upper end of this graft for the purpose of framing a tongue which would mortise into the groove already prepared in the tibia as shown by drawings (Fig 193) which prevented the graft from riding up on the tibia The upper end of this mortised tongue was shaped into an extended hook for the purpose of hooking under and internally (medullary size) to the cortex of the upper end of the tibial groove When the graft was in position this mortised joint fitted accurately be cause both the groove in the tibia and the mortised tongue of the graft were fashioned with the twin saws at the same distance apart

The graft was further secured in its position by passing the heavy kangaroo tendon through drill holes in the lower end of the tibia and tying it securely about the graft (Fig 193) The freshened surfaces of the graft on either side and below the mortised joint were held in close apposition to the periosteal denuded surface of the lower end of the tibia An attempt to close the skin over the graft disclosed the fact that the correction of this extreme deformity had so elongated the outer side of the leg and foot that the contracted skin was not sufficient to cover it and therefore the skin wound could not be closed To meet this difficulty we again returned to the trimmings of the left leg and dis sected therefrom an oval segment of skin (a Wolff graft) about 2¼ inches long by 1¼ inches wide This was sufficient to complete the skin closure and was so placed as not to overlie the bone graft or bring the skin sutures over the graft Sterile dressings were applied and a plaster of paris dressing was put over all

The convalescence was uninterrupted All the wounds healed by pri mary union and both skin graft and bone graft healed in kindly The result was most gratifying after six months the foot being corrected and held in excellent position by this improvised malleolus (Fig 194)

Haas reported a satisfactory end result twenty years after having car ried out this operation

Harmon and Fahey have summarized the various methods devised for this condition (See Fig 195)

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CHAPTER VII

PLASTIC BONE GRAFT SURGERY

THE HEAD

Simultaneous with the increasing use of the automobile and high power complicated industrial machines has come an unprecedented demand for plastic bone surgery, particularly about the head and face, where displacement or loss of bone substance may cause marked and embarrassing disfigurement The nose, the jaw, the skull, once comparatively immune to injury in days of peace, have lost this immunity, and the dreadful disfigurements of war are now paralleled by those attendant upon our love of speed By means of the autogenous bone graft however, the modern surgeon is able to repair them to a remarkable degree

Fractures affecting the patient s facial appearance from depression or other disfigurement, as a rule involve open operation with replacement of the fragments Tibial bone graft pegs or kangaroo sutures may be required to hold them in position, and in certain instances, additional bone may have to be inserted to obtain the desired cosmetic result

Replacement of Portions of the Skull by Bone Graft —The irregular rounded bony edge of a defect in the skull is freshened and the defect converted into an irregular hexagonal aperture in the following manner

The hexagon is outlined in the pericranium as close as possible to the edge of the irregular aperture (Fig 196) The thickness of the skull is then measured and a thin strip of bone is removed all around the edge of the opening with the motor saw These saw cuts should be markedly beveled to receive the graft with which the aperture will be closed While the saw is cutting, additional protection to the dura can be furnished by slipping a thin piece of sterile ivory under the bony edge

Four drill holes are now made in the cranial cortex, ¼ to ⅓ of an inch from the margin of the aperture and opposite the four lateral angles of the hexagon (Fig. 197). The motor drill is prevented from injuring the dura by inserting the tip of a small ribbon retractor or a piece of ivory between it and the skull about the opening.

All the dimensions of the remodeled aperture are then carefully taken

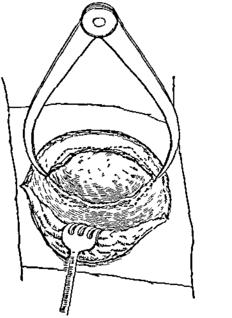


FIG. 196

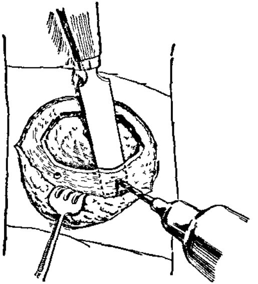


FIG. 197

Fig. 196.—The bony edge of the irregular defect in the skull is freshened and the defect converted into a hexagonal aperture in the following manner. The hexagon is outlined in the pericranium as close as possible to the edges of the irregular defect. The thickness of the skull is then measured and a thin strip of bone is removed all around the edge of the opening with the motor saw protected by a proper-sized washer. The dura is protected from the saw by slipping a thin piece of ivory under the bony edge while the saw is cutting. All the dimensions of the remodeled aperture are then carefully taken with calipers or compasses. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders.

Fig 197.—Four drill holes are made in the cranial cortex, ¼-⅓ inch from the margin of the aperture and opposite the four lateral angles of the hexagon. The motor drill is prevented from injuring the dura by inserting the tip of an osteotome between it and the skull opening From Albee, *Orthopedic and Reconstruction Surgery*, Saunders.

with calipers, and are transferred to the upper portion of the antero-internal surface of the tibia or ilium, whichever is selected as the source of the graft in accordance with the size of the graft needed. From the caliper measurements, the exact size and contour of the graft is outlined in the periosteum of the tibia with the point of a scalpel (Fig. 198). A pattern of the skull defect may be made from gutta percha tissue and used as a model in shaping graft from ilium or tibia. The graft is re-

moved with the author's small motor circular saw, the cuts being beveled to match those at the edge of the skull opening, so that the transplant will rest firmly on the skull edges and cannot be depressed upon the brain beneath (Figs 199 201)

The graft is held in place by four ligatures of medium kangaroo ten

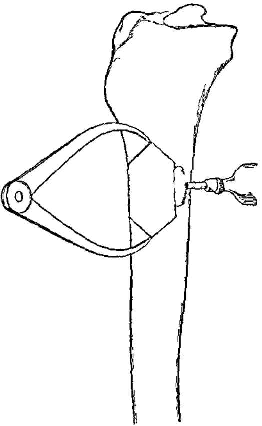


Fig 198—All the dimensions of the remodeled aperture having been carefully taken with calipers are transferred to the upper portion of the antero internal surface of the tibia The exact size and contour of the graft is outlined in the periosteum with the point of a scalpel from the caliper measurements The graft is removed with the author's small saw the cuts being beveled as are those at the edge of the skull opening so that the transplant will rest firmly on the skull and cannot be driven down upon the brain beneath From Albee ***Orthopedic and Reconstruction Surgery*** Saunders

don placed in corresponding drill holes in the edges of the graft and skull opening (Fig 207) The upper end of the tibia is selected rather than the lower, because its cortex is thinner and its surface flatter and broader A graft covered on both sides with periosteum may be obtained by the same technic from the scapula (Figs 203 205)

If the dura is lacking, the brain should be covered by a piece of fascia

of suitable size (obtained from the fascia lata of the thigh) just before the bony transplant is fixed in place. Although some surgeons employ for this purpose a thin sheet of collodion (prime) or cargile membrane, the use of these foreign bodies is not physiological and therefore is not recommended by the writer. The technic is applied to all bone defects of the head, such as old mastoid depressions following drainage operations, etc.

Adams, in a report on craniocele, describes the insertion of two tibial

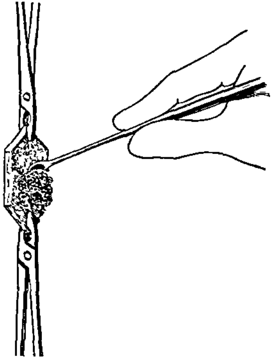


Fig. 199—The hexagonal graft is firmly held by hemostatic forceps and the marrow removed from its inferior surface by means of a sharp curet. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders.

grafts in one case, and a graft from the ilium in a second with successful osteoplasty of the bony defects.

Watson-Jones considers an autogenous graft essential in osteoplasty of the skull. However, he transplants the outer table of adjacent bone retaining a pedicle of periosteum to provide uninterrupted blood supply. I have never found any necessity nor merit for employing a pedicle as it interferes with accurate shaping of the graft.

Bone Graft for Cosmetic Purposes in Injury, Disease or Congenital Deformity of the Facial Structures.—Facial reconstruction amounts essentially to sculpturing with live tissues for material. Therefore, when

transplanting bone and soft tissues for repair of the nose, cheek or jaw, one must combine mechanical dexterity with artistic feeling for the desired cosmetic result

Correction of Deformities of the Nose —*Saddle Nose* —When there is deficiency of the bony framework, producing saddle nose, bone or cartilage grafting is indicated

TECHNIC OF CHOICE —I have obtained good results in this class of

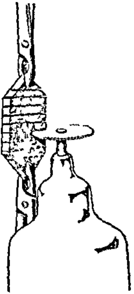


FIG. 200

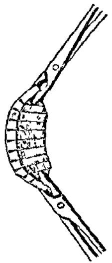


FIG 201

Fig 200 —The surgeon holds the graft *in two pairs of hemostats* and brings *its* endosteal surface in contact with the single saw whose rate of speed he controls by the foot switch The depth of the transverse saw cuts are regulated by a proper sized washer fitted to the saw The procedure is analogous to that employed by a carpenter in cutting a board to cause it to bend about a curved surface From Albee *Orthopedic and Reconstruction Surgery Saunders*

Fig 201 —By holding the graft with two strong clamps at either end, the surgeon is able *to test its flexibility as he proceeds with the transverse cutting He can thus judge very* accurately when he has produced the desired flexibility in the graft to enable it to conform to the convexity of the site of its proposed implantation From Albee *Orthopedic and Reconstruction Surgery Saunders*

case by placing a tibial graft through an incision in the tip of the nose (Figs 206, 207) By elevating the skin and subcutaneous tissues intact from side to side of the nose, the surgeon is able to bring about a stretching of the skin over the graft to the limit of pressure anemia, whereas a line of suture on the side of the nose commonly employed would entirely debar this because the blood supply from the skin is intercepted and that amount of tension would open up the line of suture The bed for the graft is prepared by thrusting a small scalpel longitudinally

through the subcutaneous tissue of the nose, half-way between the skin of the bridge and the mucous membrane beneath it, until the anterior surface of the nasal bones and then the glabella of the frontal bone are reached. The periosteum of these bones is incised in the median line, and with a small curette under the guidance of external palpation the periosteum is peeled sideways and the bone beneath scarified for a fresh contact with the upper end of the graft. A Kelly or Ochsner clamp as a dilator is inserted and the soft parts stretched forward and separated sufficiently from the bone to allow insertion of a large enough graft to correct the saddle nose completely.

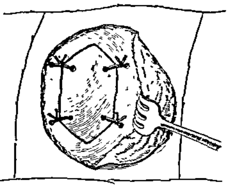


Fig. 202—The graft is held in place by four ligatures of medium kangaroo tendon placed in corresponding drill holes in the edges of the graft and skull opening. The drill-holes in the graft are best made before the latter has been cut from the tibia. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders

This graft, taken from the tibia, is frequently of considerable size and the stretching of the tissues over it is carried to the limit of pressure anemia, even though circulation has not been cut off on either side (as no external incision along the side of the nose has been made). My approach has the further advantage of not causing a scar between the eyes, or on

FIG. 203 FIG. 204

Figs 203 and 204—Lateral and anterior views of patient. In this case the projectile had produced an aperture in the right frontal region, a favorable location for repair by bone graft implantation. A wide area of scalp has been shaved preliminary to operation. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders.

the side of the nose, as is the case when the graft is put in from above downward. The short incision in the shadow of the nose and in tissues that approximate readily leaves a scar that is hardly noticeable.

In cases where it is desirable to elevate the tip of the nose forward at the same time that the saddle disfigurement is overcome the graft is made in an angular shape (Fig 206) In this instance the upper portion

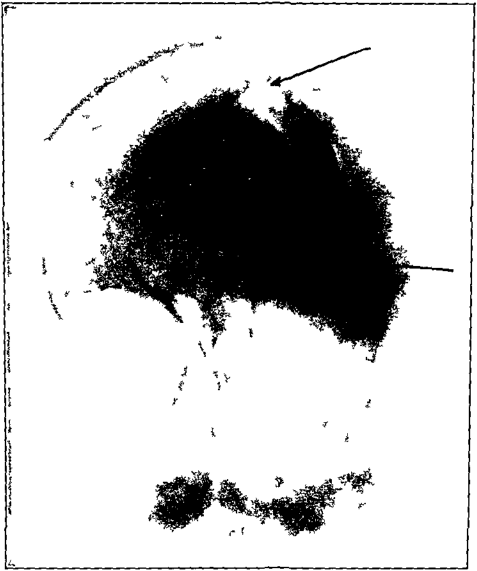


Fig 205—Same case as Figs 203 and 204 Anteroposterior radiogram taken six months after implantation of bone graft The outlines of the hexagonal graft in the frontal region are plainly seen From Albee *Orthopedic and Reconstruction Surgery* Saunders

of the tunnel in the soft parts directly over the lower part of the frontal bone is not dilated with a clamp The sharp wedge end of the upper part of the graft is forced beneath the periosteum and periosseous structures

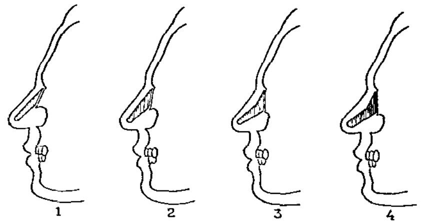


Fig. 206—Author's method for correcting nasal deformity with bone graft Diagram illustrating various shapes of grafts depending upon the degree of deformity.

over the front of the bone, and this acts as a lever holding forward the tip of the nose. The degree of corrective action in this instance depends upon the degree of angulation of the graft.

Fig. 207—X-ray, four years after bone graft in case as shown in Fig 206 Note marrow cavity developed and hypertrophy of graft at bridge of nose, *i.e.*, the point of greatest stress

Cartilages and soft parts are sometimes used instead of a bone graft. However, cartilage will *not withstand pressure, therefore in many instances,* it will be advantageous to combine bone and cartilage grafts. Cartilage is an ideal tissue *to fill out contours for cosmetic purposes.*

Loss of Substance.—A different type of rhinoplasty is called for in cases where portions of the nose have been destroyed by disease or operation. The nature of operative reconstruction varies considerably in these cases with the location and extent of tissue destruction.

Soft tissue work falls especially within the realm of the plastic surgeon. It is the cases with loss of bony framework and soft structures which concern the bone and joint surgeon.

Formerly when a pedicle was thought essential to a graft, it was also thought that the surgeon, in restoring cases of nasal destruction, must use such aids as a finger with soft parts and bone combined (Finney's operation). But, as a matter of evolution, it has been found that he can best transfer first the soft parts and then the bony framework. This latter accomplishment

allows much more latitude in technic in that one is not limited to the diameters of the finger It is also less mutilating to take both soft parts and bone from parts of the body where they will not be missed or will very shortly fill in, instead of sacrificing part of a finger The loss of a finger, even to obviate facial disfigurement, is a consideration of some moment, and is no longer necessary

The same mutilation occurs when bone and soft parts are taken from the skull or forehead as practised by Nelaton, Lexer, Konig and Schimmelbusch, and this, likewise, is unnecessary as the soft parts and bone do *not have to be grafted together*

It is preferable to supply a soft tissue bed by a two stage operation from abdomen to forearm and forearm to nose, and later to insert a tibial graft as bony framework

RECONSTRUCTION OF THE JAW

Armamentarium —In no part of the osseous system is the electric motor cutting tool more advantageous than in reconstruction work on the lower jaw (1) because of the knurly and hard character of this bone (2) its lack of weight and anvil stability making it unsuited to the use of the osteotome and mallet (3) the difficulty of immobilization, (4) the proximity of the oral cavity and (5) the smallness of the mandibular diameters All of these combine to make the highest degree of precision necessary Motor saws, drills or end mills afford this In groove and inlay work, such as is required for fractures of the jaw, instead of prying out the bone with an osteotome as would be done in a large strong bone such as the tibia, I use sharp motor drills and end mills for this purpose, removing the bone piece meal, rather than in strips of varying size from between the cuts of a twin saw which is done in larger bones In fracture cases, the small mandibular fragments recede from even light blows of chisel and mallet In fact, in all jaw work, one should trust exclusively to motor driven tools

Often there is insufficient anvil stability to withstand the impact of chisel and mallet Gillies, who uses the chisel and mallet, states that a graft taken from a brittle tibia broke twice before its shape was complete In fitting in the remains into the recesses made for it in the jaw fragments, the fragments broke This shows how essential are the proper tools Restoration of bone in the jaw demands the most exact cabinet maker s work and the expert moulding of curves which is only possible by means of the automatic machine tools

In facial surgery the cosmetic effect is frequently of the greatest

importance, and it would be impossible to shape the graft with the required delicacy without the power driven tools, since reconstruction amounts to sculpturing with live tissues for materials. When transplanting bone and soft tissues for repair of the nose, cheek or jaw, mechanical dexterity and precision must be combined with artistic consideration for the cosmetic result.

I wish strongly to recommend the use of kangaroo tendon, as against the use of wire for fixative sutures.

Congenital and Acquired Deformities.—In the face, symmetry is desirable for cosmetic reasons, and either hypertrophy or maldevelopment of the jaw may prove a real affliction. Hemihypertrophy is particularly annoying. Formerly it was not considered good surgery to remove bone

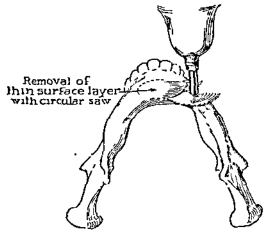


Fig 208.—Demonstrates advantage of a motor saw in shaping a flat surface on anterior surface of jaw to receive bone graft.

for cosmetic reasons, and this is not surprising in days when the surgeon had to work with hand instruments. But the motor saw affords a very quick and accurate way of removing excess bone when the facial bones are asymmetrical, or adding bone modeled with great precision when deficiency is extreme, and this should be done whenever necessary.

Congenital Deficiency or Maldevelopment of Mandible.—Extremely receding chins may have a most unfortunate psychological effect on sensitive adolescents, creating a degree of introspection which, as the wage-earning age is approached, may become a serious inferiority complex. In such extreme instances, I believe that operative treatment to build out the chin is warranted. Many such cases have come to my attention and the return to normal self-confidence, following operation, fully warranted the procedure.

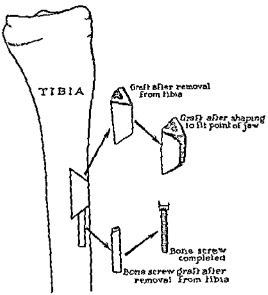


Fig 209—Method of obtaining autogenous bone graft and bone screw

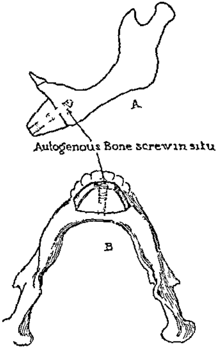


Fig 210—Onlay graft held firmly in position by bone screw which is far more efficient than a peg because of nature of diameter of mandible at this point

Onlay Bone Graft to Build Out Chin.—An incision in an inconspicuous place under the chin, following the wrinkle lines if possible, should be made. The soft parts are dissected back and the skin and subcutaneous tissues of the neck separated for a considerable distance downward and loosened so that later they can be drawn upward to cover the enlarged mandible. The graft supplies the most prominent part of the chin, and varies widely as to the size and contour in accordance with the cosmetic demands of the individual case. It varies usually from 1½ to 2 inches in length and 1¼ to 1½ inches in width (the latter becoming its antero-posterior diameter when in place). It will, therefore, be appreciated that the skin and soft parts above, and especially below the proposed site of the grafts must be loosened from underlying structures so as to readily stretch *over the graft and allow the incision to* be closed without danger of sloughing *from too much tension.*

Fig. 211.—Patient with marked recession of jaw.

Technic.—After the anterior mid-portion of the mandible has been laid bare, the next step is to prepare a flat surface to which to apply the graft, by removing a small amount of bone from the anterior apex of the mandible by means of the motor single saw (Fig. 208). The approximate diameters of the desired graft are then obtained by calipers and flexible probe, after which the wound is packed with a hot saline compress.

The upper antero-internal surface and crest of the tibia are exposed by generous incisions. A pattern of the proposed graft is then made in the periosteum by means of the tip of the scalpel blade (Fig. 209). It must be appreciated that the mechanical judgment and measuring accuracy of the surgeon's eye have a great deal to do with expediting this type of osteoplasty; indeed, in no type of case does it have more importance. The graft is removed by the single saw *following the pattern lines already made.*

It is then temporarily placed in its proposed site, the soft parts from *the neck are pulled over it, and the skin temporarily approximated with* towel clamps so that the surgeon may determine whether the contour *from the graft is cosmetically satisfactory or not.* If it proves that there should be further modeling, this is done, an assistant holding the motor

saw upon the table while the surgeon feeds the bone graft onto the saw.

When the modeling is completed, the graft is held in place upon the apex of the mandible, and if bone graft pegs are to be used, two holes are drilled through the graft into the jaw with the motor drill; or one hole, if a bone graft screw is to be used. I prefer the latter in that, by carefully forcing the screw, a close approximation of the graft to the

Fig 212—X-ray following reconstruction of lower jaw to build out chin using technic as in Figs 208 210

mandible is brought about. The anteroposterior thickness of the maldeveloped mandible at this point is small at best, and the holes are of necessity so shallow that even a closely fitting peg will not always hold well. The threads of a well-fitted bone graft screw hold most satisfactorily. For this reason the graft is much more firmly secured to the

mandible by one bone graft screw than by two pegs, and I will describe here only the bone graft screw technic (Fig. 210).

With the cosmetic graft held in place, a drill hole ¼ inch in diameter is made through it and the jaw and the threads are then placed upon its surface with the proper sized hand-driven tap, preparatory to receiving the bone graft tibial screw. Then, with the twin saw adjusted to remove a graft just large enough to make the desired screw, a strip of bone is taken from the antero-internal surface of the tibia just below where the first graft has been removed. The end of this strip of bone is made conical by thrusting it into the bone graft motor "pencil sharpener" cutter.

It is then pushed through the proper sized dowel or lathe cutter, and afterward through the die cutter which puts on the threads. It is necessary during this procedure to drip a small amount of saline upon the peg in order to facilitate the cutting of the threads.

Fig 213.—Same as Fig. 211—end result

The cosmetic graft is now held in correct position while the bone graft screw is forced home by means of a heavy Ochsner clamp, the turning of the last thread of the screw causing a close approximation of the graft to the flattened surface on the apex of the mandible, because of the head shaped on the screw by not pushing the graft quite through the peg shaper.

The skin and subcutaneous tissues are drawn up over the graft with continuous subcutaneous sutures of No. 1 chromic catgut in the underlying soft parts and the skin closed by means of interrupted sutures of horsehair. It must be realized at this juncture how important it is that the graft be held firmly in place, as there will be a drag downward because of the skin sutures being drawn up over it.

Postoperative massage is given to stimulate tissue growth, loosen overlying soft parts and to prevent any contraction from scars.

In certain cases it may be necessary at a later date, in order to improve the contour of the profile, to make a fascia, fat or cartilage grafts to fill in depressions. The application of the large graft, by making the chin more prominent, may tend to accentuate these depressions at either side of the mouth. By means of fascial and fat grafts these depressions may be filled in so as to produce symmetry of the face as shown in Figures 211-213.

ASYMMETRY OF THE JAW

When in addition to the cosmetic disfigurement there is marked malrelationship of the lower dental arch with the upper, this may be corrected by section of the short side of the jaw, thus allowing the chin fragment to be drawn forward Subsequently, the resulting gap is filled in by means of a bone graft

Before the first operation, Ivy attaches wire arches to the lower and upper teeth to provide for fixation in the corrected position A small skin incision is then made at the border of the mandible, usually beneath the origin of the first molar tooth, and with the motor saw the ramus of the jaw is severed vertically, thus permitting the chin to be pulled forward to the median line, bringing the teeth into as satisfactory occlusion as possible The teeth are then fixed in occlusion by means of wires connecting the upper and lower arches

After 10 or 12 weeks of fixation in this manner, the mucous membrane will be healed over the site of the hiatus in the jaw At this time the gap between the jaw fragments is exposed by an incision beneath the border of the jaw The fragments are grooved with the twin saw, an inlay graft in inserted by the usual technic (see page 285) and held in position with kangaroo tendon Where the hiatus is of small dimension, osteoperiosteal grafts may be used

RESTORATION OF LOSS OF SUBSTANCE BY BONE GRAFT IN UNUNITED FRACTURES OF THE JAW

Source of the Jaw Graft —For satisfactory repair, from the point of view of function, cosmetic effect, and permanency, the massive inlay graft has no rival in the treatment of mandibular ununited fractures The tibia, ilium, rib and clavicle have all been used as sources of the graft In jaw work I always use a tibial graft unless the extensive moulding of the graft requires that it be obtained from a bone of broader diameters, such as the ilium Tibial bone cells are as active osteogenetically as those of any other bone its cortex is dense and strong, and when moulded into curves, always necessary in jaw work, it retains its characteristic strength By the constant use and study of tibial grafts in numbers approximating 6,000 during the past 30 years, I have come to have great confidence in this source of graft material I believe it to be preferable to any other bone By using such strong bone one can, with relatively small diameter of the graft, exert a strong immobilizing influence upon the fragments of the jaw under all conditions And there is no use to which the graft is

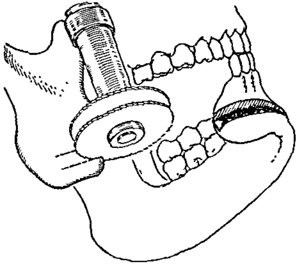


Fig 214—Groove being formed in posterior fragment. The bone is usually so hard in these jaw cases that it resists cutting with hand-tools such as osteotome and gouge, and it is necessary to employ motor-driven burrs and drills to remove the bone between the initial saw-cuts. The motor-engine is indispensable for this work. Pattern of proposed graft obtained by bending probe to conform to gutters. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders

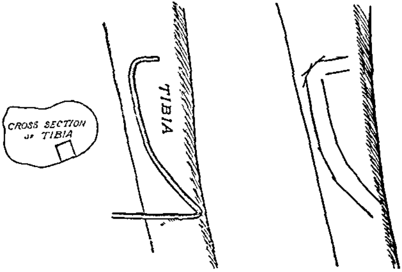


Fig 215

Fig 216

Fig 215—Pattern of desired graft transferred to tibia by flexible probe. Pattern outlined on tibia by incising periosteum with point of scalpel. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders

Fig 216—Cuts of rotary saw in tibia following pattern outlined in Fig. 215. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders.

put where, because of the limited size of the graft one is permitted to use, the strength of the graft material is so important. By using the twin saw and motor tools the graft can be inlaid and mortised in between the cortical layers of the jaw at the distal end of the gutter in the posterior fragment and a complete inlay into the anterior fragment will give very firm immobilization even though the external immobilizing influence (such as an interdental splint) may fail.

The strength of a tibial bone graft is in great contrast to that from the rib, which, owing to its spongy nature and the extreme thinness of its cortex, becomes very much weakened through loss of tubular strength as soon as efforts are made to trim or mould it. In inlay work, because of

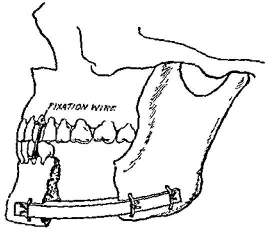


Fig 217—Represents a bone graft shaped in inlay form to the contour of the jaw for the purpose of restoring a loss of two inches of its substance This graft although much less in cross-section diameter than the lower jaw increased in size (as it always does) to the full diameter of the jaw From Albee, *Orthopedic and Reconstruction Surgery*, Saunders

the thinness of the cortex, the rib graft is apt to disintegrate or break into fragments after being moulded to the extent that is usually necessary in fracture cases with loss of substance. As an onlay to build out the chin, and in reconstruction of the nose, the rib graft may, however, prove satisfactory.

If the breadth of the tibia, adequate for the graft dimensions required in many cases, is not great enough to allow the moulding of such wide curves as are sometimes needed to repair extensive destruction even from angle to angle of the jaw, I use grafts from the wing of the ilium.

When the graft to replace loss of jaw substance is taken from the ilium, it is wise to take it from the same side as the facial injury as this enables the patient to lie comfortably on the other side immediately after operation.

The ilium is approached by the Sprengel-Smith-Petersen method, but the periosteum is *not* removed with the muscle, as it is desirable to have it remain on the graft.

Type of Graft.—Aside from the source of the graft, there is considerable difference in practice amongst reputable surgeons as to the type of

Fig 218.—Successful reconstruction of ununited fracture of the mandible with extensive bone loss. Bone graft *AB*, inserted with methods shown in Figs. 214-217.

graft used: massive inlay, onlay, sliver, osteoperiosteal and pedicle. Neither the sliver nor the osteoperiosteal grafts are suitable for good cosmetic results in jaw work. Only by means of a strong graft moulded especially for this purpose and firmly inlaid into each fragment can restoration of the proper contours of the face be attained.

INLAY TECHNIC OF BONE RECONSTRUCTION AFTER PRELIMINARY SOFT PART WORK IN UNUNITED FRACTURES WITH LOSS OF SUBSTANCE

A general anesthetic is given through nasal or pharyngeal tubes The skin incision is so placed that the graft may be covered and embedded if possible in normal, vascular, blood carrying tissues, through whose medium nourishment must be brought to the graft Scar tissue devoid of blood vessels is likely to break down and slough

After the jaw fragments are laid bare, every effort should be made at all times to avoid entering the oral cavity as the mouth is full of bacteria For this reason incision should be made low over the margin of the jaw

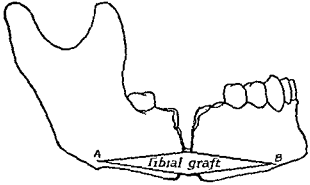


Fig 219—Modified method of reconstruction of the jaw using double wedge end graft where bone defect is not extensive

If the mucous membrane is punctured, it must be immediately sutured with great care, to avoid air being forced through during coughing or sneezing, and infection being carried deeply into the wound with the air

The ends of the jaw fragments are developed by sharp and blunt dissection The twin saw is then adjusted in accordance with the width of these fragments (Fig 214), and cuts are made back from the fragment ends for about 1¼ inches The ends of the strip of bone between the saw cuts are then severed in several places on each side by means of the small cross-cut saw, or with the end of the motor drill With a sharp, thin, narrow osteotome, the strip of bone between the above mentioned saw cuts is then removed Even this may be found difficult and the small motor saw, or burr, may be used to complete the formation of the gutter One or two small drill holes are then made on each side of the gutter in each jaw fragment, into which medium kangaroo tendon sutures are inserted

By means of a flexible lead bar or probe, the exact contour of the proposed graft is obtained. The blades of the twin saw, used for making the gutters in the jaw fragments, are then additionally separated a little

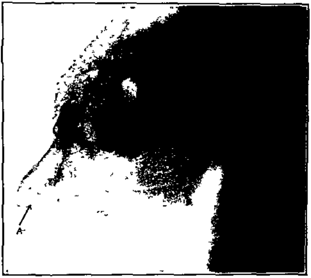
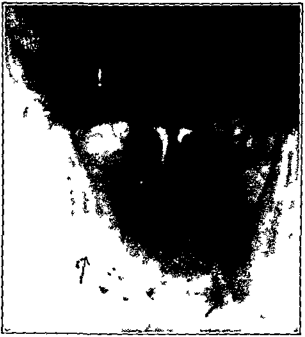


Fig. 220—X-ray showing bone graft, *AB* in position.

less than twice the thickness of the blade (Fig. 128); or, if two twin saws are available, twin saw *B* is so adjusted that twin saw *A*, which has been used to form the gutter between the jaw fragments, will just engage on

Fig. 221.—Same as Fig. 220. Solid union.

the outside of the saw-cuts in *B*. If the twin saw were not thus adjusted, the gutter would be twice the thickness of the saw-blade wider than the graft removed by the same twin saw unchanged. By adjusting the twin saw in this way, a much closer fit of the graft is secured. In this work, where the bones are so small, the graft should be as large as possible. In



A

B

Fig 222—*A* arrows indicate loss of $\frac{2}{3}$ of the body of the mandible following shrapnel wound

B complete restoration of lower jaw using U shaped bone graft (*BG*), removed from

Fig. 223.—Entire inferior maxilla from angle on one side to angle on the other, together with the overlying soft parts swept away by a fragment of an exploding cannon. Photograph *taken soon after injury. On account of loss of so large a part of lower jaw and lower lip,* patient was unable to phonate. Tongue was later drawn down to an extreme degree by the contractured tissues. From Albee, *Orthopedic and Reconstruction Surgery,* Saunders.

A B

Fig 224.—*A,* author's case, same as Fig. 223, where the whole anterior part of lower jaw *from angle on one side to angle on the other side was carried* away with all of the soft parts of the chin by a fragment of an exploding cannon See Fig 222

A large flap of skin and subcutaneous tissue has been turned up onto the chin; the pedicle is seen in *A* and *B* From Albee, *Orthopedic and Reconstruction Surgery,* Saunders.

work on large bones, such as the tibia or femur, there is not so much proportional bone loss

As has already been stated the graft is obtained from the upper portion of the antero internal surface of the tibia when possible, otherwise from the wing of the ilium (Fig 215) The upper portion of the tibia not only furnishes a broader surface, but also has a thinner cortex which is more in keeping with the thickness of the cortex of the jaw bone The flexible probe is laid upon the flat surface of the tibia and that portion of the graft which is to be situated between the jaw fragments to restore

Fig 225—The fixation plaster including the upper arm and the forearm in the region of the elbow and the top of the head above the ears is shown It is essential that the pedicle be left intact and not severed until three weeks has elapsed From Albee *Orthopedic and Reconstruction Surgery* Saunders

the facial contour is mapped out with the point of the scalpel in the periosteum

The ends of the graft which are to fit into the gutter already made in the ends of the jaw fragments are similarly mapped out, using the twin saw as a caliper guide The graft thus outlined is removed with the twin saw and single saw The motor saw should be allowed to travel its whole width into the marrow cavity before it is pushed along the length of the bone, so that contact with the marrow will furnish a lubrication to the saw

After the graft is removed the kangaroo tendon already inserted in the mandibular fragments is elevated from the bottom of the grooves the graft slipped through under the kangaroo loops and the latter then tightened down over the surface The graft is then forced into place by

means of an Ochsner clamp or bone drift and the kangaroo tendon tied; the second half-knot being locked by tying No. 1 chromic catgut about it. In cases where there is a tendency for the adduction deformity of the jaw fragments to recur and it is difficult to hold them in abduction, the end of the graft is so shaped that it can be pushed under the mandibular cortex at the distal end of the gutter (see Fig. 217). This locks the fragments in their corrected position.

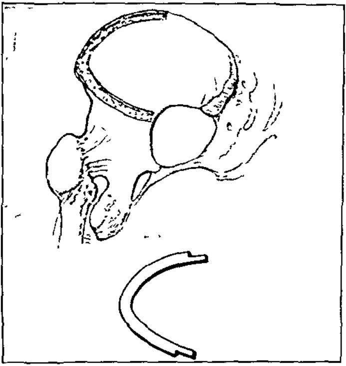


Fig. 226.—Bone graft for restoring lower jaw and site of its removal from ilium. This graft is used to repair defects of jaw in such cases as shown in Fig. 223. The author has found that, in a very large percentage of cases involving loss of substance of the lower jaw occurring in his experience in France and in civil life, the tibia is adequate in its dimensions to furnish grafts for satisfactory repair. However, in cases where large portions of both sides of the jaw are lost, the ilium has to be utilized to obtain grafts with the necessarily marked curvature. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders.

The deeper structures are pulled over the graft by a curved needle with No. 1 chromic catgut. The skin is closed by small sutures of fine silk or horsehair. A large dressing is applied, with a bandage over the top of the head (Fig. 218).

The patient is fed by a tube immediately after the operation. I have often purposely put in a graft whose diameters at the mandibular hiatus were larger than necessary, and after fixing the graft in place by the

kangaroo ligatures, and temporarily approximating the soft parts, to study the symmetry of the two sides of the face, have again retracted the soft parts and shaped the external contour of the graft as needed to produce a good cosmetic effect. The single motor saw is used for this purpose.

Postoperative Treatment.—The wire fixation on the teeth is kept in place for about 12 weeks after the graft operation. After 8 weeks, the upper and lower teeth can be unlocked at intervals to permit gentle exercise and to stimulate bone consolidation. Union should be firm in about 3 months, after which it is usually possible to have the missing teeth replaced by an artificial denture (Figs 219-228).

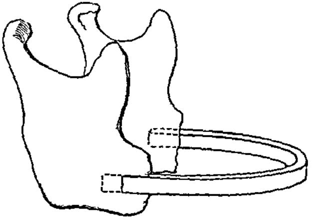


Fig 227—Diagram of graft from ilium shown in Fig 226, in place From Albee, Orthopedic and Reconstruction Surgery, Saunders.

SYNTHETIC FORMATION OF THE THUMB OR FINGER BY TRANSPLANTATION OF TISSUES

One of the most important functions of the hand in picking up objects, buttoning the clothes, eating, and other routine activities of daily life is the opposing of thumb and finger. Without the thumb the usefulness of the finger is greatly impaired, and *vice versa*, in the absence of fingers, the thumb becomes an almost useless appendage The loss of this opposing function is a tragedy to the artisan whose livelihood depends on manual skill. One of the most striking instances of the value of tissue grafting is the synthetic formation of a new finger or thumb. This may be necessitated by congenital absence of a digit, or destruction of the same by accident or disease.

The following technic, devised while Chief Surgeon at U.S. General

Hospital No. 3, during the war, has proved most effective and has since been applied following industrial accidents.

In cases of severe laceration of the hand by high explosive or crushing injury, with or without infection, which necessitate the amputation of the four fingers with all, or the greater part, of the adjoining metacarpal bones, all function as a hand is destroyed, since the thumb, the only

Fig. 228.—Same case as Figs 222-227, after a large area of skin and subcutaneous tissue had been transplanted from upper surface of shoulder to the chin, and an extensive U-shaped graft from the side of the ilium inlaid for the restoration of the whole anterior portion of the jaw from the angle on one side to the angle on the other.

The object of the soft tissue transplantation was two-fold: (1) to furnish sufficient soft tissue in which to later embed the iliac bone graft, and (2) for its cosmetic results False teeth will still further improve the cosmetic result. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders.

remaining digit, has no power of prehension in the absence of any opposing surface (Figs. 229, 230).

An entirely new digit is constructed by means of synthetic transplantation of tissues. This "finger" or thumb provides in each instance the necessary opposition, transforming the hitherto helpless stumps of hands into useful members.

Technic.—After preparing the fields of operation with iodine, a rec-

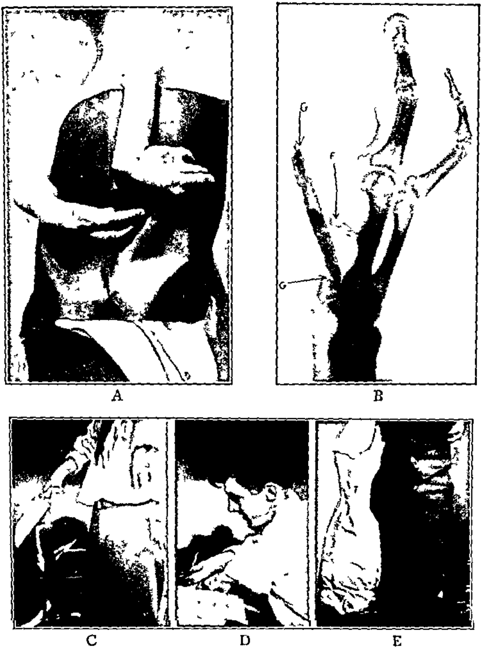


Fig 229—*A*, photograph of patient with congenital absence of thumb and malformation of other fingers

B following author's plastic operation to reconstruct the thumb G denotes tibial bone graft implanted into carpal bones Soft tissues for thumb obtained by skin pedicle from abdominal wall F is a bone graft screw inserted at second operation when original graft became loose at its carpal attachments This was the result of patient using hand for hard labor

C, end result showing patient's ability to grasp objects, previously an impossibility

D, patient using thumb to write

E, using new thumb to lift a 25 pound sandbag

tangular skin flap, 2½ x 3 inches, including full thickness of skin and subcutaneous tissue, is turned up from the chest or abdominal wall and sutured into the form of a tube or finger. Its pedicle, the full width of the base, is left attached at its base to the boneless finger, in order that adequate blood supply may develop. The portion of chest or abdominal

A B

Fig. 230.—Stump of left hand before plastic operation, showing complete loss of the four fingers and adjoining metacarpus. *B* shows the only remaining digit, the thumb, fully extended. In *A*, the thumb is shown fully flexed. Note the absence of any opposing surface for contact with the thumb, as a result of which nothing can be grasped. To restore function of hand, the construction of a new digit was undertaken by means of synthetic transplantation of tissues (See Figs. 231-234). From Albee, *Orthopedic and Reconstruction Surgery*, Saunders.

wall left uncovered by the removal of the graft is closed by swinging plastic skin flaps, black silk being used for suture material (Fig. 231).

An incision is made on the stump surface of the hand over the os magnum and extending down through the soft tissues nearly to the bone. To these soft parts are sewed the cuff of skin and soft parts forming the boneless finger, great care being taken to secure exact approximation of corresponding layers of graft tissue to host tissue, *i.e.*, skin to skin and subcutaneous tissue to subcutaneous tissue. In order to avoid traction upon the boneless finger, the hand is then immobilized by incorporating

the shoulder, arm and chest in a plaster of paris spica, the axilla having been first thoroughly padded with cotton The thumb is left projecting so that the circulation of the limb may be observed

Four weeks later, when adequate blood supply is established between graft and host tissues, the cast is removed and the hand and boneless finger are disengaged from the thoracic wall by dissecting loose a circular flap of skin 1½ inches in diameter, in addition to the finger portion

The antero internal surface of the upper portion of the left tibia is

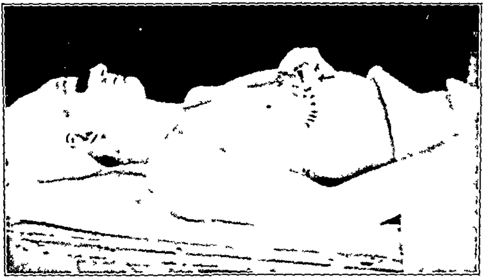


Fig 231—First operative step in tissue transplantation A rectangular flap of kin and subcutaneous tissue was turned up from the chest wall and su ured into the form of a finger Its end was approximated to the edges of an incision in the stump of the hand made over and down to the distal surface of the os magnum by the Italian plastic method A ped cle (ind cated by arrow) was left attached to the chest wall to supply nourishment to the newly implanted parts until circulat on with the hand should be thoroughly estab lished (This photograph was taken at the time of removal of the plaster of paris spica in which hand arm and shoulder were incorporated for four weeks following the first operation) From Albee *Orthopedic and Reconstruction Surgery* Saunders

laid bare by a curved incision about five inches in length A graft three inches long and about ⅛ inch wide is mapped out with the scalpel in the periosteum, one end being cut wedge shaped Following the indicated pattern, saw cuts are then made with a motor saw completely through the cortex to the marrow cavity For purposes of increased osteogenesis, a sliver graft about 1/16 inch in diameter may be removed from the side of the gutter formed by the removal of the first graft Both grafts consist of the full thickness of the periosteum, the cortex, the endosteum and as much of the marrow substance as can be obtained, *i e*, as much as will cling to the graft when it is pried out of its bed These grafts are then

dropped into a normal saline solution of about 40° C., while the new bed of the graft is being prepared.

Now the boneless finger is tunneled by means of a small scalpel down *to the os magnum. With an osteotome, a wedge-shaped mortise ⅛ inch*

Fig 232—*Roentgenogram of left hand with grafted finger,* showing implantation of the two tibial bone grafts In this operative step, the boneless finger, cut loose from the chest wall, was first tunneled by means of a scalpel and a wedge-shaped mortise was made *in the* distal-radial surface of the os magnum with an osteotome. Into this mortise a wedge-ended tibial graft, 3 inches long and about ⅜ wide, was firmly driven, in the position shown in this figure. A sliver graft (indicated in illustration) was affixed along the ulnar side of graft No 1, for purpose of "bone-seed," or increased *osteogenesis. The skin was closed with* interrupted silk sutures

This radiogram was taken four weeks after the transplantation of the tibial grafts which have now become firmly united to the bones of the hand.

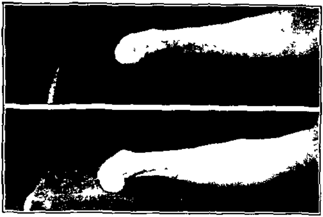
Note the amount of bony extremity originally absent in the hand and the resulting loss of function, to restore which the synthetic transplantation of tissues was undertaken. From Albee, *Orthopedic and Reconstruction Surgery,* Saunders.

deep is made in the distal-radial surface of this bone. The large graft is then taken from the salt solution and with a mallet its wedge end is driven into the mortise just made in the surface of the os magnum until it becomes firmly engaged in the cancellous structure of this bone. The sliver graft is thrust through the soft parts of the boneless finger along the ulnar side of the graft No. 1, and, by means of the author's "bone-

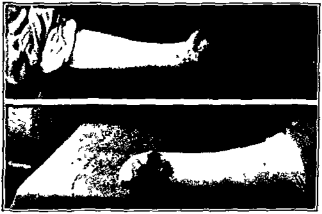
Fig 233—The patient uses both hands in the natural manipulation of knife and fork From Albee *Orthopedic and Reconstruction Surgery* Saunders

Fig 234—This photograph shows the cooperation of the two members in an act requiring strength and dexterity From Albee *Orthopedic and Reconstruction Surgery* Saunders

set its end is affixed in the mortise already mentioned (For position of the bone grafts see radiogram Figs 232, 229) The end of the graft is then covered by means of the circular skin flap referred to above and sutured over to form the end of the new finger The hand and finger are



A



B

C

Fig 235.—*A*, loss of all digits from war injury.
B, following author's operation for neoplasty as shown in Figs. 231 and 232.
C, end result Patient can now handle small objects because of *ability to flex stump* of wrist against synthetically constructed thumb.

immobilized by means of a metal splint and left undisturbed for six weeks (Figs 233 235)

Much attention has been devoted to the reconstruction of the mutilated thumb The methods employed may be classified as follows

1 Methods entailing the transplantation of tissues from a distance
   (*a*) Pedicle graft of skin, tubed, and stiffened by a free bone graft
   (*b*) Transplantation of a toe
   (*c*) Transplantation of the ring finger from the opposite hand
2 Methods using the remaining parts of the injured hand
   (*a*) Making a cleft between 1st and 2nd or between 2nd and 3rd, metacarpal bones—called "phalangization"
   (*b*) Finger transplantation
   (*c*) Rotation of two of the remaining fingers
   (*d*) A combination of two or more of the above methods

A brief review of the methods that have been used in reconstructing thumbs follows

In cases in which the metacarpals remain, a deep cleft has been established between the thumb and the second metacarpophalangization (Huguier in 1852, Verrall, Arana Perthes) The metacarpal, but not the carpal origin of the two adductor muscles of thenar eminence, must be detached and the lining of the cleft is made by swinging skin flaps into it, or by supplying skin from elsewhere as practiced by Thiersch and Wolfe or by supplying pedicle grafts The cleft has been further widened by removing the second metacarpal

The index or long fingers together with a part of the whole of the metacarpal have been transplanted to the stump of the metacarpal of the thumb or to the trapezium, but without conservation of all nerves, tendons, and muscles (Perthes Verrall, two cases in 1919, no joining of tendons or nerves, Dunlop in 1923, used pedicle skin from abdomen for the cleft)

The little finger (Wierzejewski) and the index finger have been rotated by means of osteotomy through the metacarpal into a position to oppose the thumb or the hand, or to oppose each other (Lauenstein, 1890, Perthes)

In cases of loss of index and long fingers the thumb has been made to approximate the little finger by altering the direction of its metacarpal and deepening the cleft (Klapp, 1912, Lyle)

Transplantations of new digits from a distance to substitute for a thumb have been made from the ring finger of the other hand and from

the second toe (Nicoladoni, 1898, tendon function retained; Joyce, 1917, two cases from ring finger; von Eiselsberg; Krause; Klimm).

New thumbs have been made from pedicle skin grafts, tubular or not, from the abdomen and stiffened by a bone graft from the tibia, contacted to or driven into the carpus (Nicoladoni, 1897; Schepelmann; Ritter; Payre; Albee; Pierce).

In case of loss of the fingers, a digit or post for the thumb to work against has been reconstructed on the stump of the hand by the pedicle skin graft and bone graft method (Albee, 1919, skin flap from shoulder with part of clavicle, flap from chest, and bone from tibia).

In total loss of the hand, graft taken from the abdomen and stiffened by a tibial bone graft served to build the useful digit. An offset has been reconstructed in these cases on the side of the radius which worked against the ulna by the motion of pronation (Henry, 1928). Also a cleft has been made between the radius and ulna, so these units could work against each other by their own muscles in a pincher action like the mouth of a crocodile (Krukenberg).

One should not forget that in the function of a hand, motion and sensation are of equal importance and this is especially true of a thumb. The hand, which is our sense organ of stereognosis, is guided in its work by muscles, joint, pain, and temperature sense and by the sense of touch. We are all familiar with how awkward and useless our hand becomes when numbed with cold. When the nerves to the digits are severed the handicap to the workman is great. He is awkward and fumbles and drops objects. His hands are like the legs of a man with locomotor ataxia and cannot functionate without visual guidance. Therefore, the thumb to be reconstructed should have, if possible, normal sensation.

In most cases the reconstructed thumb will acquire a slight degree of sensation, but it will be greatly limited as to the degree of stereognosis. A finger with volar nerves cut is permanently anesthetic. Strangely enough a little better sensation will be acquired in a whole finger grafted on, or one made from a tubular skin pedicle, than will follow in a finger after the two volar nerves have been severed. This is apparently because more free nerve endings start to grow down the new digit. On the other hand, when the two main nerves alone are severed these become sealed by neuromata, and the unsevered minor nerves already have their normal terminations, so that no free nerve ends are available to grow down the finger.

Unless we graft the natural nerve supply with a digit or suture the two volar nerves of the new digit to those at the base of the lost digit, the proper degree of sensation and trophic influence will not be acquired.

A prosthesis as a substitute for a thumb is usually discarded, as it has no motion and no sensation

In Bunnell's method of reconstructing the thumb, the normal nerve and vascular supply are preserved and all of the muscles and tendons of the old thumb are attached in their former arrangement to the new thumb

Bunnell's Method.—Case of H W W aged 49 years a year previously a circular saw amputated the thumb through its carpometacarpal joint and the index finger through its proximal phalanx Patient had not been able to work at his trade of carpenter since the accident

All structures necessary for making a new thumb were present and fortunately were then of no benefit to him as they were nonfunctionating They consisted of the following There was a long enough portion of the second ray for good length of thumb composed of the second metacarpal and half the proximal phalanx of the index finger This had attached to it two flexor and two extensor tendons which could act on the metacarpophalangeal joint and also on the new joint to be constructed between the base of the second metacarpal and the trapezium In addition he had normal blood lymph and nerve supply for the new thumb which could be preserved He also had the normal specialized sense organs of the skin of the hand which convey impressions of stereognosis in a refined way For attachment to the transplanted member were all five muscles of the thenar eminence with their normal nerve supply the long flexor tendon of the thumb and the three extensor tendons also the four tendons of the index finger Thus eight tendons and five thenar muscles which were already balanced were more than ample for stability and strength and most of them were already educated for use in thumb function

Operation—April 10 1929 skin flaps were so constructed that a flap from the dorsum of the hand was utilized to close in the raw surface of the newly constructed thumb Another flap from the palm was made to cross the bottom of the cleft between the new thumb and the hand so as to maintain the depth of the cleft

The old scars in the hand were excised The two tender neuromata of the nerves to the amputated thumb and the two to the amputated index finger were dissected out and cut off after the main trunks had been ligated and injected with alcohol to prevent reformation of neuromata

The remains of the index finger which consisted of half the proximal phalanx the two flexor and extensor tendons nerves and blood vessels and the metacarpal were transplanted *en masse* to the position of a thumb ample blood supply being left in the posterior and anterior pedicles The proximal end of the second metacarpal was disarticulated from the carpus and transplanted to the trapezium to form the new joint With it was taken the lower 3 inches of the tendon of the extensor carpi radialis longus and this was passed through drill holes in the trapezium and metacarpal so as to encircle the joint and to stabilize it against dislocating The upper or muscle end of this same tendon was fastened in the forearm to the extensor carpi radialis brevis tendon for added strength of extension of the hand The surface of the second metacarpal is well adapted to rest on the saddle of the trapezium and in the correct rotation for apposition

The original three extensor tendons of the thumb were united to their respective

sides at the base of the transplanted metacarpal by passing the sutures through a drill hole in this bone. Good osteoperiosteal and tendon contact was established. The original flexor tendon of the thumb was dissected out and united to the two flexor tendons of the index finger so as to give added strength of flexion to the new thumb.

In the transplantation of the index finger the volar digital nerve to the second interdigital cleft was slit longitudinally up to the base of the palm, so that sensation would

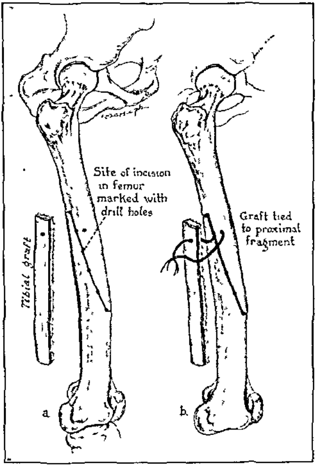


Fig. 236*A*.—Compere's method of leg lengthening showing the tibial bone graft being applied. From Compere, "Indications for and against the Leg Lengthening Operation," *J. Bone & Joint Surg.*, July, 1936, 18, 3:700.

be preserved both on the radial side of the long finger and the ulnar side of the index finger. The fork of the volar artery to this cleft was cut and ligated on the long finger side to give richer blood supply to the new thumb. The posterior interosseous muscles in the first and second cleft were preserved with their same attachments and the anterior interosseous muscle in the second cleft was also preserved with its attachment. All the small thenar muscles were dissected out and attached to the metacarpal of the new thumb.

The new thumb was completely enclosed in skin by the flaps from the dorsum and palm of the hand Eventually there was a denuded area about 1 inch wide and 5½ inches long running obliquely across the dorsum of the hand through the newly constructed cleft and around across the palm This was filled in with a whole thickness Wolfe graft taken from the skin of the abdomen Rubber sponge pressure was used in the dressing

Result—The thumb has two movable and stable joints a metacarpo-trapezial and

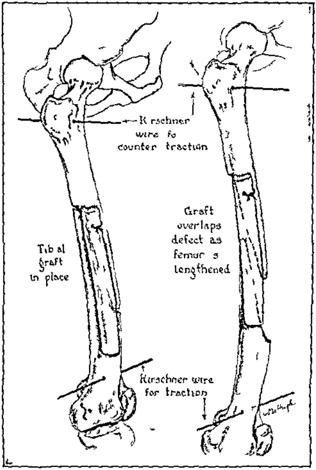


Fig 236B—*Tibial bone in place as an onlay graft, both before and after lengthening has* been obtained illustrating the splinting effect and advantage in obtaining more rapid and stronger bone union From Compere Indications for and against the Leg Lengthening Operation *J Bone & Joint Surg* July 1936, 18 3 700.

a distal joint The latter which formerly was the proximal joint of the index finger has 25 degrees of motion and is in a functionating position The thumb is exceedingly strong in all its movements as it has the combined strength of the index finger and thumb thus having eight functionating tendons instead of the normal four It is also controlled in its movements by the thenar muscles attached to its metacarpal and functioning

A feature of great importance is that the new thumb has natural sensation and vascularity as the nerves and blood vessels have been transplanted with it With the faculty

of stereognosis it is most valuable to the patient in his work. The hand is covered with good skin throughout, is free from deforming cicatrices, and is painless. Patient is now again able to pursue his trade of carpentry.[1]

Schepelmann's Technic.—A section of the fibula is removed and transplanted into the abdominal wall. Then, by raising the integument around it, this is gradually mobilized until there is obtained a pedicled skin flap containing the bone transplant in the center. At a third step, this pedicled flap is sutured to the properly prepared base of the mutilated or missing finger, and the position secured by plaster bandage. After ten days, a gradual separation of the pedicle from the abdominal wall is carried out.[2]

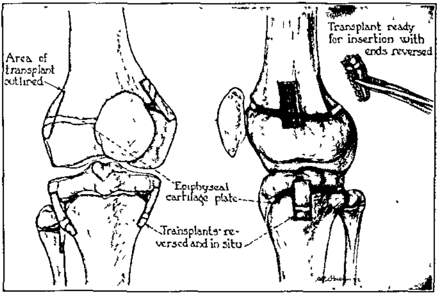


Fig 237.—Sketch of technic of epiphyseodiaphyseal fusion. Transplants reversed and cartilage chiseled out From D B. Phemister, "Arrestment of Longitudinal Growth of Bones," *J. Bone & Joint Surg*, Jan, 1933, 15, 1:11.

I prefer to transplant the soft parts in the form of a tubular graft *first, and after full vascularization from the hand has been established,* insert the bone graft.

CORRECTION OF LIMB INEQUALITY

Leg Lengthening.—There are three avenues of approach to the difficult problem of correcting limb inequality—shortening the well limb, lengthening the retarded femur or tibia, and thirdly, epiphyseo-diaphyseal arrest.

Compere's findings are entirely in accord with the author's experience.

[1] S. Bunnell, *Surg, Gynec & Obst*, Sept, 1924, 39:259-274.
[2] E Schepelmann, *Ztschr. f. orthop. Chir.,* 1916, 35 827.

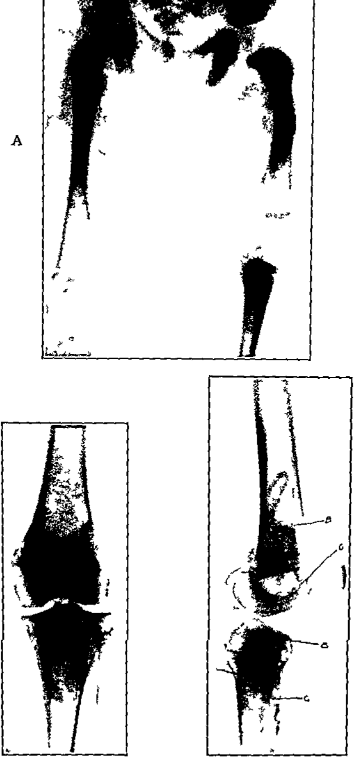


Fig 238 —*A* x ray taken in early childhood showing marked disparity in leg length.
B ten years after author's operation to arrest growth by method described on page 311 Inequality of limb has been considerably reduced Note fusion of epiphyseal cartilages
C x ray following operation to arrest growth as shown in Fig 237 Note bone graft (*BG*) across epiphyseal cartilage obtained from adjacent shaft

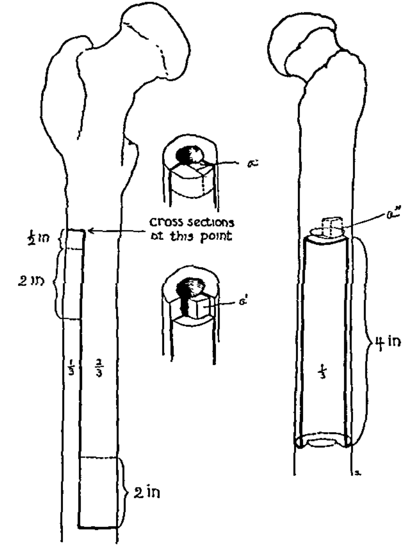


Fig. 239.—Author's method of leg lengthening or shortening by telescoping one fragment *into another so as to maintain contact at all times.*

Leg lengthening is at best a hazardous procedure and the operation is not attempted unless the following conditions are fulfilled:

1. Shortening of more than one inch that produces impairment of gait.
2. Young adult or adolescent patient.
3. Good to normal muscle power at hip and knee and a stable foot, or one that can be stabilized surgically.
4. Absence of previous infection of bones of the short extremity.
5. Refusal of patient to permit, or other contraindication to shortening of the longer leg.

Contraindications to leg lengthening are as follows

1 Shortening of less than three centimeters

2 Age of patient under fifteen or sixteen years

3 Any patient who is sufficiently tall to permit shortening the longer leg or who will not be psychologically disturbed because of loss in standing height by

(a) Epiphyseal growth arrest or

(b) Resection of a segment of the femur of the long extremity

4 Weak or paralyzed muscles of the hip or knee

5 Shortening so marked that maximum lengthening will not sufficiently equalize the extremities to enable discarding of shoe elevation or other appliance

6 History or clinical and roentgenographic evidence of previous osteomyelitis in the short leg or other pathology in the bone to be lengthened i e fibrocystic disease

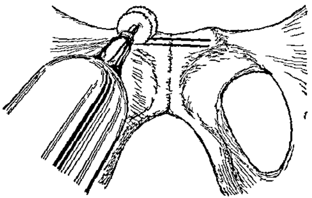


Fig 240—Author s twin saw grooving the pubic bones on either side of the symphyses (No 1) From Albee Enlargement of the Parturient Canal by Bone Graft *Surg Gynec & Obst* June 1928 46 845 By courtesy of *Surgery Gynecology and Obstetrics*

7 Congenital short leg as in absence of part of the bone to be lengthened or other severe deformities in which an artificial limb may give a better functional result

Careful selection of patients in accord with these principles will aid in diminishing incidence of nonunion infection malalignment etc In order to protect the patient against these untoward complications Compere advocates internal splintage across the line of osteotomy with a strong tibial graft A more rapid and stronger bony union is obtained because contact between the diverging fragments is not lost Figs 236 *A* and 236 *B* illustrate the technic the details of which are as follows

1 A Kirschner wire or Steinmann pin is inserted anteroposteriorly through the trochanter

2 An elastic bandage is applied from toes to groin to drive the blood from the limb

3 An Esmarch bandage is then applied above the pin as a tourniquet and the elastic bandage is removed from the leg

4 A posterolateral incision is made and the femur is exposed by separating the muscles from the lateral fascial septum

5. The periosteum is stripped only as far as the length of the osteotomy, to avoid devascularizing the bone.

6. An oblique rather than a Z-type of osteotomy is used, as there is less danger of fracture. This cut may be made through the outer cortex with the motor saw.

7. The osteotomy should be only about two inches longer than the desired lengthening.

8. Holes, one-eighth of an inch in diameter, are drilled at intervals of one centimeter through the medial cortex in the line of osteotomy.

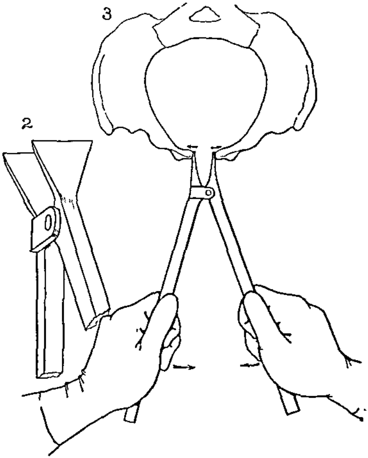


Fig 241.—Nos. 2 and 3, spreader used for spreading pelvis after the severance of the symphyses. From Albee, "Enlargement of the Parturient Canal by Bone Graft," *Surg, Gynec. & Obst*, June, 1928, 46:845. By courtesy of *Surgery, Gynecology and Obstetrics.*

9. A metal pin or wire is inserted through the femur above the condyles.

10. A tibial onlay bone graft is next added to splint the osteotomy site and to aid in union. (See Figs. 236 *A* and 236 *B*.)

11. A cast is applied which includes the body and opposite leg, and which extends downward onto the upper third of the thigh of the short extremity, in which portion the proximal wire or pin is incorporated. This pin and cast immobilize the proximal fragment and reduce the variables in maintaining accurate alignment. The ring of the rigid

Thomas splint is firmly attached to the cast and the lower pin to the splint by means of the turnbuckle This affords control over the lower fragment [3]

Operative Arrest of Growth —The procedure of arrest of growth by operative fusion of the epiphysis with the shaft of the long bone has more to recommend it than leg lengthening, below the age of twelve Growth may be sufficiently retarded in the longer extremity so that the limbs will be of equal length when adult life is reached A careful assay must be made of the situation before the extent of operative work is determined One must reckon with the amount of shortening the age of the patient, and the cause of the shortening In early childhood, operative destruction of the lower femoral epiphysis may be sufficient to obtain equality of the limbs at maturity However, when the surgeon is confronted with a considerable degree of shortening in an older child it will be necessary to "go the limit" and arrest growth in the upper and lower tibial, the upper and lower fibular and the lower femoral epiphyses The upper femoral cartilage does not contribute sufficiently to the growth of the limb to warrant the dissection necessary for its exposure

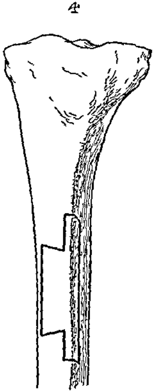


Fig 242 —No 4 shape of graft obtained from tibia From Albee Enlargement of the Parturient Canal by Bone Graft *Surg Gynec & Obst* June 1928 46 845 *By courtesy of Surgery Gynecology and Obstetrics*

The technic of the operation is one of simplicity compared to the difficult procedure of leg lengthening The lower epiphysis of the femur is exposed by two short medial and lateral incisions and the cartilage carefully removed by the electric drill and curettement A sliding graft, 1½ inches in length, is obtained from the adjoining shaft and is then inlayed into a bed already prepared with the twin electrical saw or thin osteotome The same process is carried out in the upper tibial epiphysis and if necessary, in the lower tibial epiphysis (Fig 237)

Phemister reported a series of twenty patients subjected to epiphyseodiaphyseal fusions for the purpose of equalizing the length of the lower limbs but postoperative observations were of insufficient duration to evaluate end results (Fig 238)

[3] Compere Indications for and against the leg lengthening operation" *J Bone & Joint Surg* July 1936 18 3 692 705

Shortening of Bones to Correct Inequality of Length.—Shortening of the longer limb is feasible in the adult when there is no objection to decreasing the stature of the patient. A Z-shaped osteotomy is performed, sufficient bone resected and the bone ends coapted with autogenous bone screws made from the resected fragments. A bone graft screw may be used to immobilize the fragments. This may also be done by telescoping one-third of the shaft from one fragment into two-thirds of the fragment of the other (Fig. 239). These may then be immobilized by bone graft screws.

5

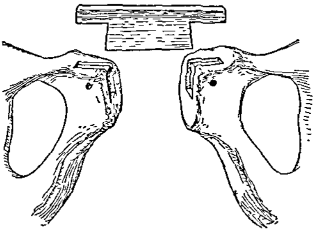


Fig 243—No. 5, bed of graft. Note the drill holes for the insertion of heavy kangaroo tendon; also the graft ready to be inlaid From Albee, "Enlargement of the Parturient Canal by Bone Graft," *Surg, Gynec. & Obst*, June, 1928, 46.845. By courtesy of *Surgery, Gynecology and Obstetrics*.

Radical resection of a block of bone should never be done with metal or wire fixation because the urge to union is diminished by shortening of the bone with subsequent removal of end thrust pressure upon the fracture surfaces.

SMALL PELVES—ENLARGEMENT OF PARTURIENT CANAL BY BONE GRAFT

Reasoning *a priori* from extensive experience in the modification of the contours and dimensions of the skeleton, enlargement of the pelvis by bone graft to increase the parturient diameters presents no more difficult a mechanical problem than many which are daily solved in the operating room of the plastic bone surgeon. Its feasibility has long appealed to the

author, but not being an obstetrician, opportunity to work up any considerable series of cases has been lacking

In seven cases, the author has enlarged the pelvic diameters by placing an inlay graft between the symphysis pubis, after forcing them apart one and one half inches In all cases the desired result was obtained the ability to bear children by normal delivery

One of the patients was six months pregnant when referred to the author A child had previously been delivered at full term by craniotomy, and the patient had been told that she could not have further children except by caesarean section The fact of pregnancy naturally increased the difficulties of the inlay graft operation but in spite of this, recovery was uneventful and she delivered a normal child

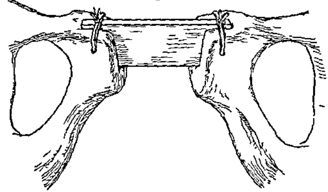


Fig 244—*No 6 tibial graft inserted with kangaroo tendon sutures in place* From Albee Enlargement of the Parturient Canal by Bone Graft *Surg Gynec & Obst*, June 1928 46 845 By courtesy of *Surgery Gynecology and Obstetrics*

The author believes that the graft method possesses distinct advantages over symphysiotomy and pubiotomy In the cases treated, he found that considerable pressure had to be exerted by a specially designed spreader in order to forcibly increase the size of the pelvis, and after gaining the increase, to hold the bones apart while the graft was being inserted Judging from his experience in these operations, the force required to separate the bones any appreciable amount is great, and after symphysiotomy this force must come wholly from the wedging effect of the head being forced downward by the muscles above

Another advantage of the inlay graft method as compared to symphysiotomy and pubiotomy is that the latter has to be repeated at each pregnancy, whereas the enlargement of the pelvic ring by bone graft is a permanent enlargement

Technic.—The technic is shown in Figs 240 to 244 In enlarging the

pelvis, *the strength of the graft is most important.* Care must be taken that it is sufficiently strong to withstand the pressure of the bones as they attempt to spring back to their old relationship.

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CHAPTER VIII

ARTHRODESING BONE GRAFT OPERATIONS[1]

KNEE

Tuberculosis.—Arthrodesis is advantageous in properly selected adult cases of tuberculosis of the knee as well as in children when the progress of the disease and destruction of bone has not been controlled by conservative types of treatment. My feeling, as well as that of many other surgeons having wide experience with such cases, has changed materially during the past few years in this respect. I now believe that, even in young children, when it is impossible to control the advance of the disease by conservative means, operations to fuse such knees should be resorted to.

Formerly it was the consensus of opinion that erasion operations on the knee should not be done under 18 years of age, but in recent years most competent members of the profession have done the erasion operation even in young children where the extent of the lesion made it necessary. I am in accord with this latter attitude. By closely conforming to the joint surfaces and removing the hyaline cartilage with a small amount of cancellous bone, the epiphyseal cartilage is not seriously interfered with, nor growth retarded as much as was formerly supposed.

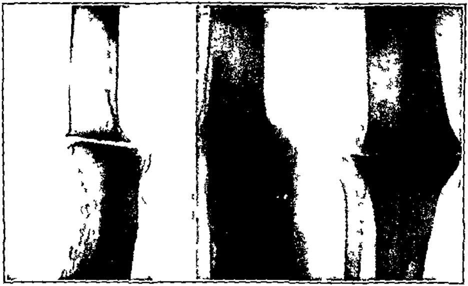
In the adult, one is not confronted with the question of epiphyseal growth, and in long-standing cases, angular deformity resisting correction by the usual conservative measures, may readily be remedied by operation to produce firm bony union between femur and tibia.

Formerly *excision* of the knee was undertaken with the prime object of removing all tuberculous tissue, the production of ankylosis being considered of secondary importance. This theory had several unfortunate

[1] For spine see Chapter III; for hip, Chapter IV.

results it led to excessive removal of bone The diameters of the bone incisions were made above the expansion of the femoral condyles and below the tibial head, thus lessening the diameters of the opposing surfaces of the femoral and tibial fragments This, together with periarticular structures, induced by the long axis of the limb being decreased, prevented firm contact of the cut bones with its stimulus to bony union The result was unnecessary extensive shortening and many nonunions

So much tissue was removed that it was often impossible to approximate the incised bone ends satisfactorily (Fig 245) There was always



A B

Fig 245—*A* nonunion 1 years duration following complete excision of knee Illustrates untoward result of this procedure Not only jeopardizes union but absolutely debars future arthroplasty

B sliding graft upward from the tibia (same case) with excellent result and solid union From Albee *Orthopedic and Reconstruction Surgery* Saunders

the possibility of not removing all tuberculous tissue Excision had an additional disadvantage when being applied to individuals who had not reached full growth, in that it entailed complete removal of the epiphyseal cartilage in both bones, thus producing a marked amount of shortening in the operation itself, and added to this the loss of growth which would normally come from the epiphyseal cartilages

Today, the theory of treatment is reversed, bony ankylosis being considered of greater importance than removal of all tuberculous tissue, inasmuch as this ankylosis arrests the tuberculous process

Even though the tuberculous involvement of bone leads deeply into

the condyles of the femur or the head of the tibia in the form of tracts, excessive removal of bone and consequent extreme *shortening* should not be resorted to. These tracts may or may not be curetted, as the surgeon deems best. But in any event one should not remove sufficient bone from the condyles of the femur or the head of the tibia to include these *tracts entirely.*

Arthrodesis of the Knee.—*Technic of Choice.*—A tourniquet is applied to the upper thigh, and a U-shaped approach used, reaching from one femoral condyle to the other, with its convexity downward, crossing the patellar ligament about one inch above its insertion.

Exposure of the joint is obtained by dividing the patellar ligament and

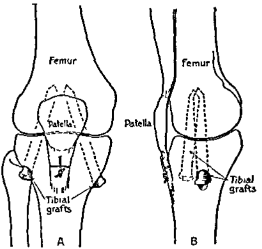


Fig 246—Method of erasion of the knee joint for tuberculosis and other pathology. The diseased part of the patella is removed and the rest of it left *in situ* to be used in a possible future arthroplasty to restore motion. The tibial and fibular fragments are then held together and immobilized by two peg grafts removed from the tibia lower down.

dissecting up and turning back the deep structures overlying the joint. The crucial ligaments, if present, are divided as well as the lateral ligaments of the joint, and the upper end of the tibia is drawn forward and the leg flexed.

The patella is turned up. If it has become united to the femur or tibia, it may be necessary to chisel it loose. The infected synovial membrane and soft parts are carefully resected or excised. With a narrow-bladed, hand bow saw, the cartilage and a little of the cancellous bone are removed from the condyles of the femur, following the conformation of the articular end of the femur.

The same thing is then done to the upper end of the tibia, thus producing two rounded curved surfaces which fit into each other. This is an

advantage and simplifies the technic, particularly in adjusting alignment of the tibia and femur, in that we have a circular convex surface fitting into a concave surface In adjusting the position of the tibia and femur, one can (by following the joint contours) get a few degrees of flexion and at the same time secure a better contact of the cut bone surfaces more easily than if he sawed the bone off square. Furthermore, a little of the length of the limb is preserved in this way. The infected posterior part of the patella is then removed with the same saw

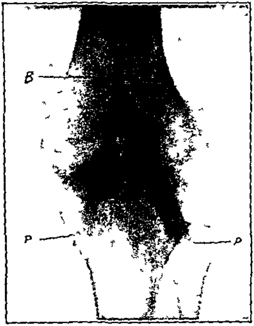


Fig 247

Fig 248

Fig 247.—Bony ankylosis of tuberculous knee following arthrodesis by means of two bone pegs (*BP*) as shown in Fig 246

Fig 248—Lateral view of knee joint firmly ankylosed by bone pegs after failure of long-continued conservative treatment (See Fig 245*B*)

If one decides to employ a bone graft, it is obtained through a skin incision lower down over the tibia, or a vertical extension from the mid-portion of the U-incision, the tibia is laid bare and the crest removed by means of converging cuts of sufficient length to make either one or two bone graft pegs, as the surgeon chooses At present I use two grafts, ½ inch in diameter, as illustrated in Figs. 246, 247, 248

The knee is extended, the saw-cut surfaces of the femur and tibia are brought into intimate contact with the knee flexed about 10 degrees (or about 170 degrees). If the surfaces do not fit quite accurately, then more bone may be removed by the hand bow saw. While the tibia and femur

are kept in the desired position with the optimal amount of flexion, one or two drill holes (as required) are made with the large half-inch motor drill, opposite the tubercle of the tibia obliquely through the upper portion of the tibia into the condyles of the femur, care being taken not to drill too obliquely, so that the drill will come out into the popliteal space.

The drill is then left *in situ,* to hold the tibia and femur in the proper position to receive the tibia bone graft peg later. The crest of the tibia is then palpated, a suitable straight portion is selected and laid bare by an incision slightly to one side. With a single motor saw, converging cuts are made, to secure a graft of the proper size for conversion into a bone graft peg by the half-inch dowel shaper. Each peg should be approximately three inches long. In making the peg, it is first held in the pencil sharpener cutter, then later pushed through the dowel cutter. If two pegs are used, with the drill still in place, peg No. 1 is driven into hole No. 1 in tibia and femur by means of a mallet and the Albee bone graft drift. The drill is then removed from hole No. 2 and the bone graft peg inserted as in No. 1. The drill holes should be staggered or oblique to each other so as to immobilize cut surface of femur to tibia more firmly. The peg or pegs, when driven home through the cancellous bone of the tibia and femur, hold the tibia and femur in close apposition and firmly immobilized. It not only serves to secure perfect immobilization, but it adds an osteogenetic influence as well as providing a vascular-conducting scaffold across the hiatus between these bones, thus leading to early union.

Some fear has been expressed that these bone graft pegs may become involved with tuberculosis; but in an extensive experience of thirty years, I have found that they never do. The reason for this may be that cortical bone has a certain immunity to tuberculosis.

The use of any foreign material, such as metal spikes or clamps, to secure arthrodesis is objectionable as the removal of the metal at a subsequent operation is necessitated in a large percentage of cases.

Following arthrodesis by the bone graft method, the patient can be up and walking without weight bearing in his plaster cast with the aid of crutches, in six weeks' time. The plaster cast should be left on for 8 to 10 weeks. The cast should extend from the groin to the toes. The bone graft peg produces such an exact immobilization of the tibia on the femur that it is not necessary, as a rule, to include the pelvis in a hip spica.

I have been particularly impressed with this in observing patients following operation before and since I began putting in these pegs. Before inserting the pegs it was always necessary to include the pelvis in the plaster of paris dressing. If this was not done, constant pain from the slightest motion was complained of, because of inadequate immobiliza-

tion After adopting the bone graft peg, I found that in most instances a plaster to the groin was ample The patients never complain of pain from moving in bed following the operation with the pegs

The tourniquet should not be removed until the plaster of paris dressing has been applied up to its level The importance of leaving on the tourniquet until after the application of a large compression dressing and the fixation plaster of paris splint up to the tourniquet cannot be emphasized too strongly This applies not only to every knee operation, but to every extremity operation where this measure of temporary hemostasis is employed

Henderson s statement that, in adults all tubercular knees of advanced pathology should be operated on is I believe, absolutely correct The profession has been rather slow in arriving at this opinion

The employment of a bone graft peg to hasten and insure union in the original operation is a very sound procedure Numerous cases operated on by others without inserting a bone graft have come to me later because of nonunion, and I have had to use an autogenous peg to secure union the patient thus being submitted unnecessarily to two operations

Planning Arthrodesis with View to Future Arthroplasty —Because I believe that in most cases arthrodesis should be performed in such a way that future arthroplasty will be possible, if it later becomes feasible I do not approve of methods which remove the patella or use it as a graft (Henderson and Fortin Girdlestone and Hibbs *et al*) This statement should not, however, be misinterpreted as advocating frequent resort to arthroplasty on old tubercular knees, for such a procedure must always be approached with conservatism and due caution There are only a small percentage of cases in which it is feasible I should recommend waiting at least three years before considering an arthroplasty on an old tuberculous case, and then the case must be selected with the greatest care as there is real danger of relapse of the old tubercular condition The bone in and about the site of the joint must be shown by x ray to be homogeneous in structure before arthroplasty is permitted To meet the exigency of a possible future arthroplasty, I now preserve the patella, but all the infected bone is cut off its posterior surface

Arthrodesis with Inlay Graft —This procedure is designed as an alternate operation for the treatment of tuberculosis where complete excision has resulted in nonunion with loss of bone

The order of procedure for procuring and placing a bone graft is here reversed, the graft being removed *prior* to the preparation of its bed in the recipient host bone, on account of the danger of soiling the tibial field if the tuberculous knee joint is first entered A tourniquet is applied

to the upper part of the thigh while the limb is elevated. The field of operation, which is prepared by the iodine method, should extend from the ankle joint to well above the knee joint (Fig. 249).

1. The graft is removed from the tibia in the prescribed manner. In this particular instance its width is determined not by the condition of its recipient bed but by the width of the medullary canal of the bone from which it is obtained. The object is to get a graft as wide as possible, from the antero-internal surface of the tibia; in length, it should measure 4 to

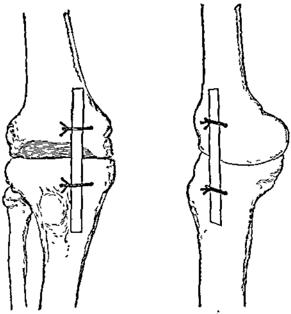


Fig 249—Alternate method of arthrodesis of tuberculous knee where previous resection operation has resulted in nonunion (see Fig 245). Inlay graft is inserted as described in text From Albee, *Orthopedic and Reconstruction Surgery*, Saunders.

5 inches. It is placed in salt solution until wanted. The wound in the tibia is then sutured and dressed.

2. The *incision* of the knee joint is U-shaped and reaches from one femoral condyle to the other, with its convexity downward, crossing the patellar ligament about 1 inch above its insertion.

3. *Exposure* of the joint is obtained by dividing the patellar ligament and dissecting up and turning back the deep structures overlying the joint. The crucial ligaments, if present, are divided as well as the lateral ligaments of the joint, and the upper end of the tibia is drawn forward and the leg is flexed.

4. *Removal* of *articulating surfaces* of tibia and femur and the posterior surface of the patella is accomplished by cutting transversely with a narrow bladed bone saw. The tibial head is made into a cylindrical

surface concave from before backward, the femoral condyle, into a cylindrical surface convex from before backward, to fit the concavity of the upper cut end of the tibia These surfaces are then exposed.

5 The *graft bed* is prepared with the author s circular twin motor saws adjusted twice the thickness of the saw blade nearer together than when removing the graft, by cutting across the central point of the apposed tibia and femur, half of the bed being formed from the former and half from the latter Its size should correspond to the tibia graft The strips of bone between the saw cuts are severed distal to the joint with a small motor-saw (author's cross cut saw) and removed with a narrow chisel

6 *Placing and Securing the Graft*—With the small motor drill holes are drilled in the femoral condyles and head of the tibia on either side of the gutter and strong kangaroo tendon sutures are passed ready to be tied over both ends of the graft The graft is placed in its bed after the holes are drilled, the sutures placed and pulled up from the bottom of the gutter in large loops to admit of its passage The sutures are then drawn taut and tied

7 *Closure of the incision* is made in the manner described elsewhere, the patellar ligament having been re united with chromic catgut

It is to be noted that only sufficient bone is removed from the articulating surface of the tibial tuberosities and femoral condyles to furnish closely approximated raw bone surfaces and only apparent and easily accessible tuberculous infected soft tissues are cut away, together with whatever synovia can be easily reached with curved scissors No undue effort is made to remove all tuberculous bone so that very little additional shortening results from the operation Both sinuses are cleaned out with a curet If the patella is found to be tuberculous the diseased part is removed or, if too extensively involved it is enucleated and discarded

This procedure, which was formerly the operation of choice in tuberculosis of the knee, has been abandoned in favor of utilizing two bone pegs (see page 318)

However, where a previous radical resection has been attempted with failure to produce fusion it will be necessary to employ an inlay graft after approximating the tibia and femur as much as possible, in order to span the hiatus with an active osteogenetic bone graft and overcome part of the shortening The technical problem is not unlike that arising in nonunion of bone with extensive bone destruction

Henderson's and Fortin s Technic—Henderson and Fortin expose the cancellous bone on both tibia and femur, remove the patella and use it as a bone graft to hasten union The amount of shortening is 1 inch

The skin incision extends about two-thirds of the circumference at the joint line, crossing just below the patella. The skin is dissected so as to clear the patella, and the joint is opened by severing the patellar ligament and the capsule, the incision being carried far enough back on both sides to permit acute flexion of the knee on the thigh. This movement opens wide the cavity of the joint and discloses the degree of involvement. The patella is dissected upward and is usually removed and kept sterile to use as a graft, or in certain cases it may be left attached and used with a pedicle.

The suprapatellar pouch and the synovia at the margins are thoroughly removed. An incision is made through the soft tissues embracing the upper end of the tibia so that the saw can be introduced, and enough of the upper end of the bone is removed to expose fully the cancellous bone. If abscesses are found in the bone, they are thoroughly curetted, the membrane lining then removed, and the cavity swabbed with iodine. Care is taken to saw off the upper end of the tibia squarely. The saw is then introduced into the condyles, no great care being taken to have the angle accurate, as we expect later to remove enough bone to provide the proper angle.

The knee still being fully flexed, the upper end of the tibia is pulled forward on the femur, thus exposing the posterior capsule which is dissected out. It is believed essential to remove as much as possible of the affected tissues. More bone is then removed from the condyles, the amount depending on the angle of election, usually ten degrees flexion. This piece of bone is excellent for a graft as it is cancellous and rich in bone-forming properties. It is carefully kept warm in hot saline packs. Two small vertical incisions are made, one on each side of the median line in the leg about 12 cm. below the upper end of the tibia, and carried down to the bone. Two wire nails are driven in a slanting direction through these incisions upward into the tibia until their points can just be seen beneath the surface of the bone. The chisel is driven vertically down along the anterior margin of the upper end of the tibia and the tissues with a good sized leaf of bone pried outward, making a trough about two centimeters deep, if there is enough of the prominence of the condylar area of the femur, but often this prominence is lacking, so that it cannot be done.

All is now ready for the coaptation of the end of the bone at the desired angle. The ends are brought together and held firmly while the wire nails are driven through into the femur. The ends of the nails are left protruding through the skin. The graft is then pushed down in the trough prepared for it in the tibia; thus it has bony contact on two sides. It can be moulded somewhat, as it will bend considerably without fracturing. If a flap has been secured on the femur, it is tucked within the resulting crevice. If there is no such crevice, the graft is moulded to the femur and held in place by catgut sutures extending from the soft tissues of the femur to the soft tissues of the tibia. The remnants of the capsule are brought together as completely as possible and the skin closed. The leg is held vertically, care being taken to maintain the angle of flexion, and a thick dressing is applied firmly. The tourniquet is then removed. A plaster of paris cast is then applied, extending from the toes to the groin. Canvas strips for suspension are incorporated in the cast at the foot and the knee.

The patient is put in bed and the leg suspended to an overhead frame so that the leg is free of the bed and the suspenders tend to force the lower fragment against the upper.

Suspension is maintained for three weeks, at the end of which time the top half of the cast is removed, the leg carefully lifted out, the stitches removed, and the bottom half of the cast cleansed, and relined with fresh cotton dressing. The leg is replaced at the same angle as before and the wire nails removed. A clean dressing is applied to the

knee and a few wraps of plaster bandage put around the old cast Six weeks after the operation a new cast which is lighter and has shoulder straps to relieve the weight of the leg is applied"

Comment—1 The diameter of the patella provides an insufficient graft

2 It is preferable to leave patella *in situ* for future arthroplasty

Intra and Extra articular Technic of Hibbs

A U shaped incision is made to sever the patellar tendon close to its insertion and the entire flap including the patella and patellar tendon is turned upward The patella is denuded of its tendinous attachments by dissecting around the circumference leaving the bone adherent by a small central pedicle All cartilage is removed from the patella femur and tibia A bed for the patella is then prepared by chiseling on the femur and tibia and the patella is implanted by wedging it in these grooves as the knee is extended The patellar tendon is then sutured and the wound closed The joint proper is invaded to a slight extent only the patella acting as a graft to unite anteriorly the femur and tibia With the patella in this position a perfect bony bridge is formed between the tibia and femur This is a distinct advantage as there is less disturbance of the tuberculous process and less surgical reaction The healing process is hastened there is less drainage and the chances of secondary infection or relighting an active process are materially decreased When a sufficient osseous bridge is difficult to obtain by employing the patella alone osteoperiosteal grafts from the tibia are used to reinforce fusion These grafts are attached to the anterolateral aspects of the tibia and femur[3]

MODERN ATTITUDE TOWARD TUBERCULOSIS OF THE KNEE

Girdlestone of Oxford made a thorough review of the practices of the leading surgeons in all countries in the treatment of tuberculosis of the knee

He divides all cases into three groups, based on anteroposterior and lateral stereoscopic x ray findings (1) with osseous foci irritating but not yet infecting the joint (extra articular), (2) with osseous foci opening into the joint and discharging tuberculous bacilli into it (focal articular), (3) without visible osseous foci (nonfocal) Extra articular operation on a truly extra articular focus will save the joint, but on a focus which falsely appears extra articular may lead to its ultimate infection with pyogenic organisms For the second group of cases, operative fusion is definitely indicated For group 3, particularly in children, conservative treatment will lead to complete or almost complete restoration of function

[2] M S Henderson et al., *Surg Clin N Am* 1921, 1 1483
[3] R. A Hibbs et al *Ann Surg* 1911, 53 406

When such a bony focus has opened into the knee, consensus of opinion is that arthrodesis should be performed at a time chosen in view of age, local and general condition.

Purely synovial tuberculosis offers good hope of obtaining full restoration of function; but only prompt, effective, continuous and prolonged treatment will prevent synovial tuberculosis from becoming osseous, and for this reason treatment should be started while the diagnosis is only provisional. In an early case it may be important to make more than a provisional diagnosis, but "hesitation in instituting immobilization has led many a child down the broad and easy way that leads to destruction of the knee joint."

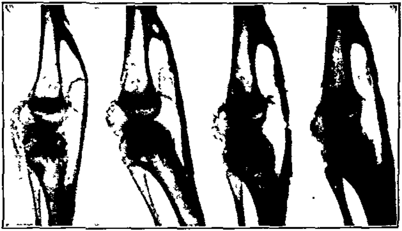


Fig. 250.—Mondolfo's method of extra-articular arthrodesis of the tuberculous knee by bone graft fusion of patella to tibia and femur. From Mondolfo, Sylvano, "Resezioni atrodesi nella tuberculosi del genacchio," *Archino Italiano di Chirurgia*, Aug., 1938, 49.241.

The dangers of operation can be listed as due to operating on cases unduly septic. I cannot agree with conservative enthusiasts who say that excision is never necessary, nor with radical enthusiasts who produce an erasion of the knee but forget that active disease still exists and demands conservative postoperative treatment.

Girdlestone advises against doing an arthrodesis in the presence of a sinus. It should, however, be realized that there are different cases and the only way the sinus can be closed is to "take the bull by the horns" and do an arthrodesis without a bone graft, however, at the primary operation. Calvé does a preliminary saucerization with resection of the sinus tracts and paraffin flavine dressings.

Statistics from many surgeons indicate that bony ankylosis follows "excision" in an average of 88 per cent of cases, and adds that "if a limb

with a soundly ankylosed knee is a mile behind a normal limb, it is a hundred miles ahead of the very best thigh stump'

Although Girdlestone's survey indicates a preponderance of opinion against attempting arthroplasty to produce motion on a previously ankylosed tuberculous knee, I have found, as already stated, that in carefully selected cases this operation gives excellent results and, when feasible, certainly is of immense advantage to the patient The x ray appearance of the bone adjacent to the joint should have complete homogeneity of structure without vacuoles or bone cavities (See also Fig 250)

FUSION OF THE KNEE IN CHARCOT'S DISEASE

Mather Cleveland and A de Forest Smith report 4 cases of Charcot's disease of the knee in which they were able to surgically fuse the knee Solid bony fusion resulted four to six months later in three of the cases, and the results were very satisfactory The fourth case was too advanced and should not have been operated upon These results compare very favorably with cases in which the fusion operation was performed for tuberculosis and poliomyelitis

Not a little doubt is justifiable as to the possibility of obtaining bony fusion in a Charcot joint The results in this series are sufficiently encouraging to warrant trying the operation in selected cases Weight bearing in plaster was allowed at the end of six to eight weeks The author has used the inlay method for fusing such joints with encouraging results

OSTEOARTHRITIS

Surgical fusion is recommended only when the joint is severely affected because in the average case fixation of the knee by brace and careful management are sufficient to relieve pain until spontaneous fusion occurs (For technic, see page 318)

CONGENITAL DEFORMITIES OF THE FOOT

Congenital Clubfoot—As the changes in bone and muscle are less marked in the infant and increase in severity with every year of growth, corrective treatment obviously should be begun at the earliest possible moment Indeed, to emphasize the importance of this point I have often said to students that if, at the time of labor, the accoucheur finds a foot or breech presentation complicated by the presence of congenital club-

foot, he should begin corrective manipulation of the foot before the birth of the head.

In infants, the chief obstacles to reduction are offered by the internal lateral ligament of the ankle, the plantar ligaments and fascia, the tendons of the tibialis posticus and anticus, and the tendo achillis, the astragaloscaphoid and calcaneoscaphoid ligaments, and by the malformation of the astragalus and other bones of the foot. All these obstacles are removable in infants by tenotomy, fasciotomy, syndesmotomy, manipulation and immobilization. In most cases in which treatment can be begun early and kept up with regularity, operations other than simple tenotomy are, as a rule, unnecessary. Emphasis is placed upon the importance of grasping the lower part of the leg, just above the ankle joint, firmly with one hand while with the other hand the foot is forcibly stretched and everted. This precaution is observed to prevent the tibia from being fractured.

In adults, one is confronted with all the obstacles pertaining to infants, and also the *following: (1) abnormal shape of the bone*, especially downward and inward twist of the neck of the astragalus and subluxation of the cuboid and scaphoid; (2) more or less obliterations *of pre-existing joints, e.g., an overgrown astragalus with contracted tibio-*fibular mortise; (3) formation of a new joint; (4) fixation of the ligaments and tendons in abnormal position. On account of diminished elasticity in the adult, bone sections must be resorted to in most instances.

Long, Slender, Relapsed Clubfoot.—To correct this long, slender type of relapsed clubfoot with marked varus and moderation adduction of the forefoot, I insert a bone graft wedge between the split halves of the scaphoid bone.

Technic.—FIRST STEP.—The deformed foot and the leg having been prepared for operation and a tourniquet securely applied above the knee, the equinus is first corrected by tenotomizing the tendo achillis. This enables the operator to force the foot into dorsiflexion on the leg and bring the heel down.

The next step, when no true bone operation is performed, is the thorough stretching out of the varus by manipulation, either manual or with the Thomas' wrench, with or without the wedge-block as a fulcrum. The *foot is then so lax as to be easily placed in an overcorrected position;* but obviously, if reliance is placed upon the external correction alone, relapse will take place. This is prone to occur following the Phelps' *operation, where a free division of all soft structures is made* down to the bone, and the foot forced into valgus, leaving the wide gapping wound to heal by granulations, resulting in a contracting scar. The articu-

lar surfaces of the tarsal bones are also widely separated with no provision to prevent them from closing up again.

Having had exceptional clinical opportunity to observe a large number of relapses in clubfoot following these soft tissue operations, it became evident to me that if relapse were to be prevented, remodeling of the bony framework of the foot was essential All previous clubfoot bone operations had entailed removal of wedges of bone from the outer or long side of the tarsus, and had thus still further shortened a foot already shorter than normal The trustworthiness of the bone graft having been thoroughly proved, it occurred to me, in 1911, that the surgeon could well remodel the tarsus, in carefully selected cases, elongating the con-

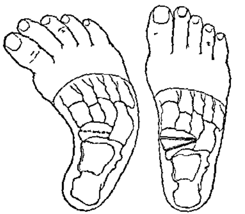


Fig 251.—An inlay wedge bone graft removed from the crest of the tibia or the cuboid of the other side of the foot and placed into the split scaphoid for the purpose of permanently remodeling the tarsus of a congenital clubfoot In this deformity the inner side of the *tarsus is shorter than its outer side and the graft is inserted to overcome this distortion in* older children and adults The advantage of guarding against relapse by remodeling the *bony tarsus is also augmented by lengthening the foot, which is always short* From Albee, *Bone Graft Surgery* Saunders

cave or short inner side of the foot by placing a bone graft wedge between the split halves of the scaphoid bone (Fig 251) At the same time that this corrects the bony deformity, it may lengthen the foot sufficiently to avoid mismated shoes Any degree of lengthening is far preferable to further shortening.

Second Step.—When the preliminary operation, described under "First Step" is completed, a U-shaped skin incision is made on the inner aspect of the foot, and the flap with its subcutaneous tissue dissected back, exposing the scaphoid bone The apex of this incision should extend well forward in the region of the great toe; or a straight incision may be made over and parallel to the long axis of the dorsum of the foot, so that the superior surface of the scaphoid is approached. What-

ever incision is employed, however, it should always be so situated, if feasible, that when the wound is closed the skin sutures do not overlie the graft. The development of the field of the bone operation should be carefully done, as the changed bone formation may cause the landmarks to be extremely distorted.

With a half-inch, thin, sharp osteotome, the scaphoid is split into anterior and posterior halves, either by a linear osteotomy through the long axis, or by a curved bone incision from above, following the general curved contour of the bone. The foot is then forced into the required degree of overcorrection, and the gap between the halves widened. All resistance by plantar fascia or other tissues is relieved by severing

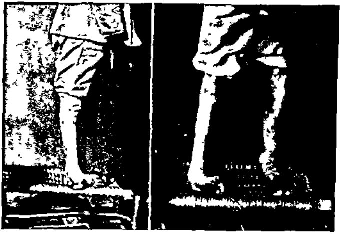


Fig 252—Marked untreated clubfoot of a boy seven years old, before operative correction A wedge-shaped graft was removed from the cuboid bone on outer side of the foot and placed into the split scaphoid after the tendo Achilles and inner portion of the plantar fascia had been severed and foot forcibly corrected. (See Fig. 253 for result.) From Albee, *Orthopedic and Reconstruction Surgery*, Saunders. (See Fig. 251.)

these structures with a scalpel through the wound already made, or by means of a subcutaneous fasciotomy through an additional tenotome wound. The width of the gap is taken with calipers, as a measurement for the bone wedge to be cut, preferably from the tibia of the same limb.

The skin and subcutaneous structures overlying the antero-internal aspect of the tibia are incised at about the junction of the lower and middle third of the shaft, this portion having a denser and thicker bone cortex than higher up. Having freed the crest from muscle attachment, and with the skin and soft parts well retracted by sharp retractors, the width and thickness of the required wedge are marked off by a scalpel cutting into the periosteum. The wedge graft is then cut with the motor saw, the two cuts being made either longitudinally or transversely, as the surgeon

wishes through the cortex of the crest, but are converged toward each other as the medullary cavity is approached

Before the graft is dislodged from the tibia, a hole for retaining sutures is made through the center of its cortex The graft is then removed from its bed with the aid of a sharp osteotome and either placed in normal saline solution until used or transferred directly to its position between the halves of the split scaphoid It should fit so tightly as to prevent any return of varus and adduction deformity when the fore foot is released by the assistant

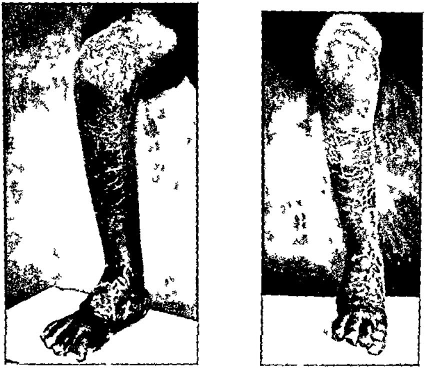


Fig 253—Same case as Fig 252 after correction of clubfoot deformity by insertion of bone graft From Albee *Orthopedic and Reconstruction Surgery* Saunders

A medium sized kangaroo tendon is threaded through drill holes in the wedge graft With the graft in the center of the tendon strand a cervix needle is threaded on each end These needles are thrust through the scaphoid edges from the cut surface side If the cortex of the scaphoid is too dense for the needles to penetrate drill holes are made to admit them The bone graft wedge is then forced into place between the scaphoid halves the tendon drawn taut and tied over the graft The subcutaneous structures are drawn together over the grafted area and the skin flap closed with plain catgut, without drainage If the deformity

is severe and the skin wound cannot be closed without too great tension and danger of slough, it is best not to attempt to approximate the flaps; but if a skin gap is left to granulate over, it should be as far from the graft as possible.

Dressings are then applied. Cotton is placed between the toes to take up the secretion; the foot and leg are covered to a point above the knee with a shaker flannel bandage or sheet wadding as a lining to the plaster of paris fixation. With the foot held in slight overcorrection, and the knee nearly to a right angle, to afford a leverage action against the tendency to relapse, plaster is then applied. This plaster dressing should remain in place for four to six weeks, when that portion above the flexed knee is cut off, the remainder being left in place for four to six weeks longer. The entire protective dressing is then removed and massage and exercise of the foot and leg instituted.

Should it be deemed advisable for the comfort of the patient, or as a means of maintaining protective fixation for a longer period, the simple clubfoot sling support is the most serviceable form of brace (Figs. 252, 253).

FOOT

Treatment of Relapsed Short Chunky Clubfoot.—In older children with this deformity, the foot being in extreme varus, with the cuboid so hypertrophied and malformed as to resist any reasonable attempt at forcible correction, even after the scaphoid is split, the problem is somewhat different. In such cases, I insert a bone graft wedge between the halves of the scaphoid, split transversely across the foot, precisely as in the technic for long slender clubfoot, except that the bone wedge is removed from the body of the hypertrophied cuboid instead of from the crest of the tibia.

A skin incision is made through the calloused skin and subcutaneous tissue down to the cuboid along the outer border of the foot, sufficiently long to give a good exposure of this bone. Having previously determined with the calipers the approximate size of the wedge desired, this wedge is outlined with a scalpel, cutting through the periosteum transversely to the long axis of the foot, care being taken to outline a wedge of sufficient width to allow full overcorrection of the foot. With the periosteal incisions as guides, the bone is then cut in slightly converging planes, with the small motor saw. The removal of the graft is then completed with a thin, sharp osteotome driven into the saw-cuts. Before dislodging the wedge from the cuboid, its center is drilled for the insertion of a kangaroo fixation suture. Then with curved scissors, the soft tissues surround-

ing the graft are freed, and the wedge removed It is placed immediately in normal saline solution, or better put directly in its position between the split halves of the scaphoid

The foot is thus divided transversely through its entire tarsal structure, which allows the forefoot not only to be swung outward at this point, but to be rotated about the cuboscaphoid ligament Thus, both adduction and varus are corrected As the cuboscaphoid ligament lies approximately equidistant from the inner border of the scaphoid and the outer border of the cuboid, it is the center of a circle of which a wedge taken from the cuboid is a sector When this wedge is placed in the gap

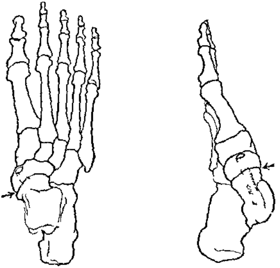


Fig 254.—Soule's technic for severe flatfoot and the pronated foot resulting from infantile paralysis The cartilage from head of astragalus and posterior surface of the scaphoid bone is removed at arrow point A tibial graft peg is then inserted as indicated From Albee *Bone Graft Surgery* Saunders

which has been formed by splitting the scaphoid and correcting the varus, it fits exactly At the same time, the gap formed by removal of the wedge from the cuboid is necessarily closed

The foot and limb are encased in a plaster of paris dressing from the toes to above the knee, with the foot well overcorrected and the knee flexed This dressing should remain on the limb for eight weeks, followed by a second plaster of paris dressing up to the knee, which should remain on for four weeks

Advantages of the Bone Graft in Clubfoot

(1) It lengthens an already much shortened foot

(2) It permanently lengthens the short side of the skeleton of the

foot, and insures in a most trustworthy way against relapse of the deformity;

(3) No joint is involved by the operation; therefore there is a minimum of interference with joint function or mobility.

. (4) It furnishes a means of permanently correcting selected severe types of clubfoot.

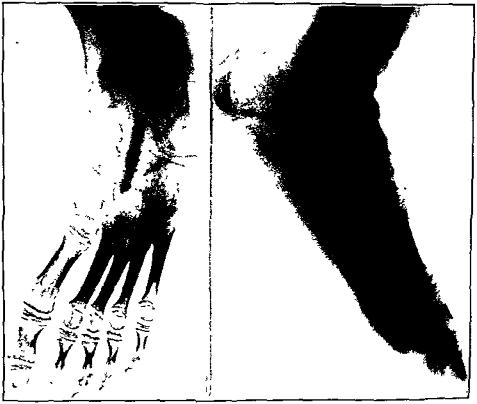


Fig. 255.—X-rays following operation shown in Fig. 254. Arthrodesis of astragaloscaphoid joint prevents relapse of flatfoot.

Paralytic and Acquired Deformities of the Foot

Flatfoot.—*Soule's Astragaloscaphoid Arthrodesis by Bone Peg for Severe Flatfoot and the Pronated Foot Resulting from Infantile Paralysis.*—The cartilage from the head of the astragalus and the posterior surface of the scaphoid bone is removed. A tibial graft peg is then inserted as indicated in (Figs. 254, 255).

This operation is used for very flail static feet, particularly in older children or adolescents.

Hoke's Operation for the Correction of Extremely Relaxed Flatfeet.

—(*Scaphoid cuneiform Arthrodesis*)—Experienced orthopedic surgeons will identify these flat feet among the varied types of flat feet by their qualities, and the failure to correct them by the conservative methods of treatment—exercises, arch supports and corrective shoes They are very flat, elongated, badly pronated, moderately abducted, and extremely flexible in the midtarsal joints and metatarsotarsal joints The flexibility is greatest in the scaphoid-cuneiform and internal middle cuneiform joints, this is of paramount importance since it interferes with the co ordinated arch lifting power of the tibialis posticus, tibialis anticus, and flexor hallucis longus

The points of major importance that one finds in these feet are (1) a short Achilles tendon, (2) extreme flexibility of the midtarsal joints, particularly the scaphoid cuneiform and internal middle cuneiform joints (3) the changed relative position of the bones The astragalus is tilted downward The upper surface of the midtarsal segment is a little con cave instead of convex, as it should be The foot is so pronated that only the vertical diameter of the inner row of bones will be cast upon an x ray plate

Fig 256 is a composite drawing of a flexible flat foot showing the relation of the bones, standing, and with the anterior foot in equinus, not standing

It is seen that the equinus position restores the normal relationship of the bones The operative corrective actions, therefore, are these

1 The Achilles tendon is lengthened,

2 With the foot in equinus, the scaphoid internal and scaphoid mid dle cuneiform joints are stiffened by bone grafting them,

3 A careful setting after the manner described below the skeleton in this way is restored to the normal, and thereafter the muscles, when trained, can hold up the arch without hindrance

Technic—The Achilles tendon is dissected leaving a covering of thin tissue sheath through an incision two inches long made along the inner border of the tendon It is cut half in two in three places as shown by the black lines on the tendon The foot is dorsi flexed the lengthening of the tendon still covers the tendon preventing adherence of the tendon to the skin It is also a mould that gives a round tendon after healing The skin is sutured Thereafter in the operation an assistant holds the foot in equinus by grasping the anterior ends of the metatarsals The anterior end of the first metatarsal is forcibly pressed in equinus The scaphoid-cuneiform joint is opened Another incision along the longitudinal dotted line is made to the bone The flaps are dissected from the bones With a thin osteotome cutting deeply the cartilage surfaces of the contiguous parts of the scaphoid internal and middle cuneiform bones are removed A rectangular section of bone one half inch deep (see black rectangle) is cut from the scaphoid and internal cuneiform bones The pieces are taken out and cut into bits A bone graft the

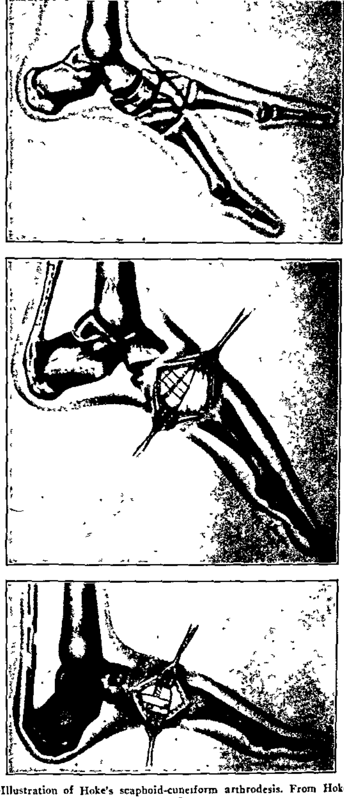


Fig. 256—Illustration of Hoke's scaphoid-cuneiform arthrodesis. From Hoke, "Operation for Extremely Relaxed Feet," *J. Bone & Joint Surg*, Oct., 1931, 13, 4 777.

size of the rectangle is taken from the tibia with a twin saw and driven into the rectangular receptacle, the bits of bone are packed into the deep and superficial spaces not filled by the graft The flaps are closed over the grafts The skin is sewed A proper setting finishes the operation Thin dressings are applied A plaster splint is made and the foot is held in equinus The first metatarsal is especially forced into equinus position by the operator s thumb pressure on the dorsal surface of the anterior end of this bone The plaster splint is moulded on the foot the cut out area receiving the heel The adja cent ends fit around the heel The plaster splint is bandaged tightly on the foot with gauze bandage The splint is moulded well under the scaphoid cuneiform joint and just before it hardens the posterior end of the heel is twisted inward After the splint has hardened the gauze bandage is removed The edges of the plaster shoe are turned up and padding inserted underneath them The foot skeleton is thus set so that the bones are normally related to one another in position

The foot is then dorsiflexed so that it makes a ninety degree angle with the leg The plaster splint prevents any change in the bone relationship in this action The cast is completed to the tibial tubercle At times it is well to apply it up to the mid thigh

Figure 256 C shows the position of the bones the graft and the lengthened Achilles tendon when the operation is finished and the cast applied

Postoperative Treatment —Two weeks after the operation the cast and dressings and skin sutures are removed The foot bones maintain their position and a cast is applied from toes to tibial tubercle This cast is put on as one usually applies a cast —*i e* with out first applying the plaster shoe This cast is removed after six weeks Massage is given for a few days A foot plate is applied fitt ng well under the scaphoid cuneiform joint Wide toed shoes are put on The patient begins to walk with crutches Massage is continued and for two weeks the patient is drilled to contract the tibialis posticus tibialis anticus and the flexor hallucis longus the instant the foot touches the ground when walking This makes a rather awkward gait It is continued for two or three months The plate is then removed

There are doubtful borderl ne cases Such cases should of course have conservative treatment first for the delay in doing the operation does not jeopardize the result Operation should not be done before eight years of age except in rare instances In adult feet the foot stra n is not always the sole cause of foot pain Tarsal arthritis is present in some cases even though it is not shown in the roentgenogram Such feet can not be cured by operation unless the tarsal arthritis is also cured [4]

Hoke did the first operation of this type in 1923

Paralytic Deformities of the Foot

Paralytic deformities of the foot are almost without exception amenable to operative correction In the residual stage of poliomyelitis treatment a ms at maximum function with min mum deformity The aim of the surgeon is the construction of a stable well balanced foot capable of function without a brace and adapted to the wearing of a ready made shoe To secure this result a rigorous preoperative study of each case is necessary The operat ve technic must include adequate skill in tendon transplantation

[4] Hoke An Operation for the Correction of Extremely Flat Feet *J Bone & Joint Surg*, Oct 1931

as well as in bone remodeling, and the postoperative treatment be carried through until the correction has been made permanent.

The problem of the paralyzed foot differs from that of the paralyzed hand in that motion is of secondary importance to stability; and for this reason, stabilizing bone operations must often be used in conjunction with tendon transplantation, in order to make the latter of any value.

It took many years for the medical profession to realize that restoration of muscle balance would not necessarily restore stability. In 1880, Nicoladoni attempted to correct a calcaneus deformity by transplanting the peroneal tendons. His operation succeeded technically, but failed to give adequate function. For years, beginning in 1896 with Drobnick's emphasis on the importance of the periosteal implantation of the transplanted tendon, orthopedic surgeons vied with one another in the multiplicity, variety and and ingenuity of tendon transplants. All these operations aimed to restore motion to the foot; and it was assumed that stability would be gained by adequate restoration of muscle balance. In America and abroad the current of thought was focused on muscular function. Indeed, in an exhaustive treatise on tendon transplantation by Biesalski and Mayer in 1913, the word "stability" is not even mentioned once in the entire volume.

The importance of stability was first emphasized in 1901 by Royal Whitman in his astragalectomy combined with posterior displacement of the foot. This operation gives a suitable foot even when most of the muscles of the calf are paralyzed. It has, however, the disadvantage of shortening the extremity from one-half to one inch. In 1922, after ten years of careful clinical experimentation, Hoke presented an operation which, in its clear conception of the mechanics of the foot, its precision and adequate restoration of stability, constitutes a great advance in the therapy of the paralyzed foot. Hoke's operation reshapes the head and neck of the astragalus in such a way as to overcome the deformity and arthrodeses the joints between the astragalus, scaphoid and os calcis so as to maintain the bony relationship in any position that the surgeon desires. Campbell in his posterior bone block to prevent drop foot, Putti in the anterior bone block to prevent calcaneus, have each contributed an important idea. (See Chapter IX, page 373.)

It is historically of no little interest to see the way in which the two schools (those advocating tendon transplantation and those advocating stabilizing bone operations) have gradually converged.

Such statements as "I favor bone operations" or "I have no use for tendon transplants" are meaningless, since what is good for one type of foot is contraindicated for another. The consensus of opinion can perhaps best be summed up by the findings of a commission appointed by the American Orthopedic Association—"that tendon transplantation should be almost invariably supplemented by stabilization of enough of the small joints of the foot to prevent or correct all tendency to varus or valgus deformity. The examination of a large number of postoperative cases has shown that the lateral deformities are of much greater importance than drop foot."[5]

Infantile paralysis tends to have an asymmetrical involvement, paralysis occurring in one group of muscles while the opposing group remains normal. When the normal group contracts, imbalance and deformity result because of lack of counterpull.

[5] Mayer, "The Operative Treatment of Paralytic Deformities of the Foot," *Am. J. Surg.*, July, 1929, 8:80-88.

Instability at the subastragaloid joint permits varus and valgus, which are often more disabling than equinus The astragalonavicular and also the calcaneocuboid joints are the seat of supination and inversion, both of which make for instability when excessive motion is possible. Much attention has been paid to drop foot, but the victims of lateral deviation are the greater sufferers Many persons with drop foot get along well with simple appliances, but those with valgus and varus do not.

Stabilization operations have, therefore, been devised to correct de-

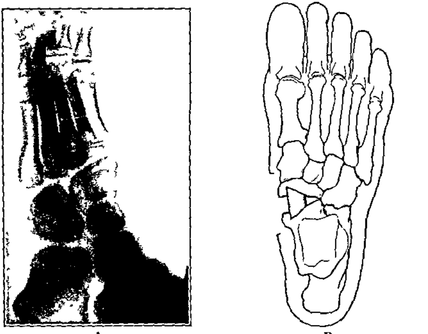


Fig 257—*A* roentgenogram of graft in place 6 months after operation for paralytic clubfoot (See Fig 253)

B, sketch of operation for astragaloscaphoid arthrodesis From Albee, *Bone Graft Surgery*, *Saunders*

formity and provide stability without the use of braces. When a joint is arthrodesed, the so-called position of choice is one which gives the most usefulness and the best appearance. The position of choice has been fairly well established for most joints. In ankylosis at the ankle, maximum usefulness is obtained with the foot slightly plantar flexed, just enough to compensate for the heel of the shoe. The foot itself functions best when it is in the midposition, neither deviating into valgus nor varus, or lying in pronation or supination

Stabilizing Operations.—Arthrodesis of the foot, although destruc-

tive of the physiologic action of the individual joints included in the operation, is, nevertheless, constructive physiologically in that the function of the foot and leg is thereby augmented. Arthrodesis necessitates the sacrifice of a joint, but such a loss is of little consequence compared to the benefit derived from the stabilizing process. Motion that cannot be controlled is useless. There are several joints in the foot that may be destroyed without materially impairing the flexibility. The joints on which arthrodesis is most often performed are the ankle, the subastragalar and the midtarsal. Forced by the recognition of the limited field for

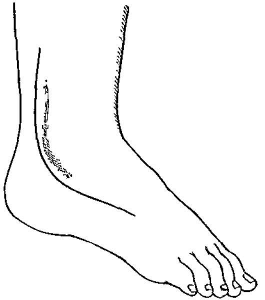


Fig 258—Incision for panastragaloid arthrodesis. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders.

transference of tendons, there has been a gradually increasing trend to stabilization of the foot by arthrodesis. The common form of arthrodesis concerns the astragalotibial, the astragalocalcaneal, the astragaloscaphoid, and the calcaneocuboid joints, individually, and in various combinations.

Several methods of arthrodesis are available, and one must choose according to the individual requirements. I have found the following the most satisfactory:

1. Panastragaloid arthrodesis.
2. Arthrodesis of astragaloscaphoid joint. (Fig. 257.)
3. The same, with fixation by bone graft peg (Soule).
4. Arthrodesis of astragaloscaphoid joint with tibial bone graft wedge in tarsus, for paralytic equinovarus.

5 Arthrodesis of the joint between cuboid and os calcis, in marked adduction of the foot

6 Subastragalar arthrodesis (between astragalus and os calcis)

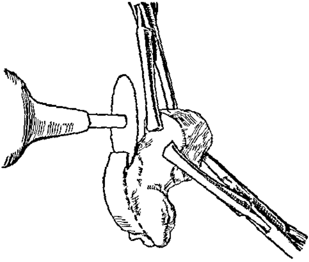


Fig 259—Removing cartilage from the astragalus before placing it back in the foot as a graft From Albee *Orthopedic and Reconstruction Surgery* Saunders

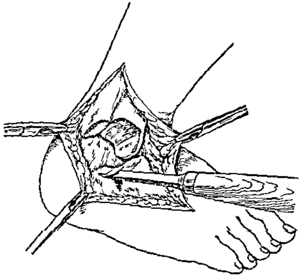


Fig 260—Removing cartilage from surface of scaphoid os calcis tibia and fibula which articulate with the astragalus Note author has modified this technic so that the astragalus is held firmly by pedicle of ligaments From Albee *Orthopedic and Reconstruction Surgery* Saunders

Flail Feet—*Panastragaloid Arthrodesis*—In 1916, not satisfied with the results obtained from astragalectomy in the treatment of flail feet, I first began to do the operation of panastragaloid arthrodesis for such

cases, and described the technic in *Orthopedic and Reconstruction Surgery* in 1919.

Panastragaloid arthrodesis is a trustworthy operation and has the advantage of establishing a somewhat elastic foot. At the same time it furnishes a sufficient amount of stability. It is indicated in cases where

Fig 261—*Complete paralysis of all the muscles controlling the foot from infantile paralysis.* The astragalus was removed and all its articular cartilage peeled off with motor saw. Also the cartilage from the bones articulating with it was removed The denuded astragalus was then put back for the purpose of making a stable ankle and foot. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders (See Figs. 259-260.)

tendon transplantation is either contraindicated or has not given satisfactory results. It is particularly indicated in a flail foot, or a foot closely approximating the flail condition.

The ankle joint having been exposed by a long Kocher incision (Fig. 258), the ligamentous structures around the entire outer and anterior side of the astragalus are severed with a small scalpel so that when the

foot is thrown into marked adduction and varus, the astragalus is easily extruded. (Figs 259, 261.)

The technic of completely removing the astragalus as described in 1919 is still feasible; but as this bone is extremely slippery and hard to hold, I have found that there is less wear and tear on the surgeon if the foot is displaced into marked adduction (as just described), thus separating the astragalus from articulating bones above and anterior, with its inferior attachments undisturbed.

The chief purpose of the latter is to prevent the astragalus from slipping to the floor, as I do not believe that the pedicle has any real merit so far as the future vascularization of the astragalus is concerned. The cartilage can then be removed, preferably with a sharp half-inch osteo-

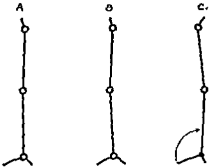


Fig 262.—Diagram indicating the center of gravity in *A*, normal foot, *B*, following astragalectomy, *C*, after panastragaloid arthrodesis Note elongation of foot in *C* with slight equinus, and hyper-extension produced in knee joint for increased stabilization of the limb

tome and mallet The motor saw may be used at times if the surgeon desires

The removal of the cartilage should be performed very thoroughly from all the articulating surfaces of the astragalus and also from those bones with which it articulates. Care should be taken not to remove too thick a layer and thus change the general conformation of the astragalus, as it is essential for it to approximate with all of its articulating bones when the foot is forced back into its normal relationship

In this operation the astragalus is used as an autogenous graft. The wound is closed and the foot and lower limb to the tubercle of the tibia put up in a plaster of paris cast with the foot overcorrected in valgus for a period of twelve weeks

In cases where the quadriceps muscle at the knee is paralyzed or markedly weakened, the foot is pulled forward to the maximum, thus lengthening the forefoot and producing a reverse lever action which throws the knee into extension when weight is borne. This is quite con-

trary to the shortening of the forefoot by the astragalectomy operation or the Dunn operation, and is most advantageous in such cases, allowing them to walk very well without a brace, or the necessity of pressing on the knee with the hand. Weight bearing locks the knee in hyperextension, and the stability thus gained is, in many instances, surprising. (Fig. 262.)

Fig. 263.—Roentgenogram of an acute tubercular ankle on a young man twenty years of age The symptoms were not relieved by a carefully fitted plaster of paris dressing and month of recumbency in bed. Pain was entirely relieved by the insertion of bone grafts from the external and internal malleoli to the posterior end of the os calcis, the cuboid bone and the internal cuneiform. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders.

ANKLE

Tuberculosis of the Ankle

Arthrodesis by Bone Graft.—For the treatment of tuberculous ankle joint and tarsus, I use a bone graft as an internal fixation splint (Fig. 265). This supports and immobilizes the diseased parts to a degree impossible by external splints, and thereby hastens the arrest of the tuberculous process.

In extensive tuberculous infection of the tarsus, where amputation is likely to be considered, three bone grafts are inserted, one from the internal malleolus to the os calcis; a second from the internal malleolus to the internal cuneiform bone; and a third from the external malleolus to the cuboid bone (Figs. 263-264).

The leg and foot are prepared for operation and a tourniquet tightly applied above the knee. A U-shaped skin flap is turned up, exposing the malleolus. A bony bed is prepared for the fixation of the joined ends of the grafts coming from the internal cuneiform bone and the os calcis.

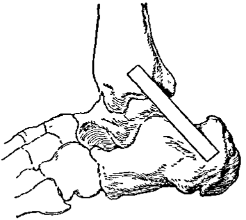
As these two grafts are to be joined at an obtuse angle at the malleolus in the manner of an inverted "V," the bed is prepared by turning one osteoperiosteal flap down and the toe upward, with motor saw or a sharp osteotome. Short skin incisions are made over the inner surface of the posterior portion of the os calcis and internal cuneiform bone, and beds are prepared in like manner for the ends of the grafts by turning up osteoperiosteal flaps Subcutaneous tunnels are made with a broad liga-

Fig 264—Roentgenogram of same case as Fig 263 taken two years and four months after the insertion of the bone grafts The symptoms remain entirely relieved and the disease apparently cured The hypertrophy and increase in density of the graft are very striking especially at *B* and *D* The fibula in which they are inserted is even hypertrophied from increased stress at *A* From Albee, *Orthopedic and Reconstruction Surgery*, Saunders

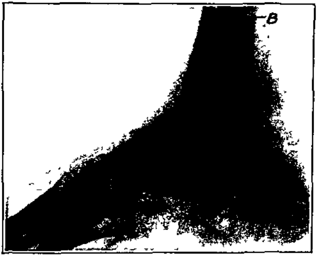
ment clamp, joining these incisions with the one over the internal malleolus.

The same procedure is carried out in forming a bed for a graft reaching from the external malleolus forward to the cuboid bone. The lengths of these grafts are determined with calipers. The antero-internal surface of the tibia of the same leg is then exposed, and with the twin motor saw, the required grafts, each ⅜ of an inch wide and the full thickness of the cortex, are removed from the central portion of this tibial surface. The ends of the two grafts which are to be joined at the internal malleolus are

mortised. This is very quickly done with the motor saw. These two grafts are pushed through the subcutaneous tunnels already prepared for them, the mortised ends joined, and then covered in by the osteoperiosteal flaps



A



B

Fig 265—*A*, bone graft arthrodesis for tuberculosis of the joints between os calcis, astragalus and tibia.

B, bony ankylosis induced by bone peg (*BP*), extending through os calcis, astragalus and tibia. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders.

which are drawn over them with interrupted sutures of medium kangaroo tendon.

The other ends of these grafts, as well as the graft implanted on the outside of the foot, are secured in place in a similar manner. The skin

wounds are closed by continuous catgut sutures, and a plaster of paris dressing applied with the foot at a right angle

Campbell s Extra Articular Fusion of Ankle Joint

A longitudinal incision is made beginning about four inches above the ankle joint and about one inch internal to the fibula and is continued downward over the lateral aspect of the ankle joint terminating on a level with the superior surface of the external cunei *form* bone (Fig 266) The superficial and deep structures are incised and the lower third of the tibia and ankle joint exposed The superior surface of the neck of the astragalus *is denuded An osteoperiosteal graft about four inches in length is removed*

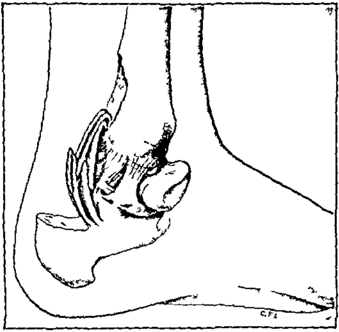


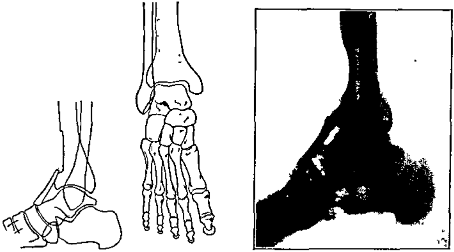
Fig 266—Campbell s posterior extra articular arthrodes s of ankle From Campbell, *Operative Orthopaedics* Mosby

from the lower third of the tibia The graft together with small shavings from the anterior aspect of the tibia is placed over the ankle joint in close proximity to the denuded surface of the lower extremity of the tibia and the denuded surface on the neck of the astragalus A second skin incision three inches in length is then made over the posterior aspect of the ankle joint to the lateral aspect and parallel with the tendo Achill s Dissection is made between the tendo Achillis and the posterior capsule of the ankle *jo nt care being taken to retract the extensor hallucis tendon inward.* The posterior capsule of the joint is incised transversely The posterior extremity of the astragalus *and the cartilage from the posterior position of the ankle joint are removed The posterior* aspect of the tib a just above the ankle joint is denuded A mass of bone is removed *from the superior surface of the os calcis and placed in contact* with the denuded poste rior surface of the tibia and denuded surface of the [illegible] Both wounds are then

closed and a plaster cast, extending from the toes to just below the knee, is applied, holding the foot in slight equinus, because with a stiff ankle this position facilitates walking.

A cast should be worn for at least three months, after which a brace may be applied. The graft may be taken from the opposite limb when the quality of the bone on the affected side is deemed unsuitable[6] (Figs. 263-266).

Tuberculosis of the Tarsus.—The midtarsal joint is the most frequently involved. The joints are infected as a rule by extension from the tarsal bones, and a tuberculous endarteritis of the nutrient vessel is often encountered. The operative treatment may be fixation of the tarsus by



A B

Fig. 267—Raffaele Zanoli Technic.
A, extra-articular arthrodesis of the foot for tuberculosis.
B, extra-articular arthrodesis—postoperative x-ray. (l'artrodesi extra-articolere Sauta Corona, Rassegna Periodica degli Instituto Ospitaliere (Milano) Raffaele Zanoli)

bone graft. The technic for fixation by bone graft is similar to that already described under ankle (Fig. 268). A bone graft may be implanted into the healthy bones on each side of the focus of disease, thus spanning it. The diseased tissues may or may not be removed, according to the surgeon's judgment. If the diseased focus is removed, a bone graft may be modeled to fill in the deficiency and be inlaid into contiguous bone on each side, thus preventing malformation of the foot resulting from loss of support by the removal of the infected bone.

[6] Willis C. Campbell, *A Textbook of Orthopedic Surgery*, W. B. Saunders Co, Philadelphia, 1930, p. 230.

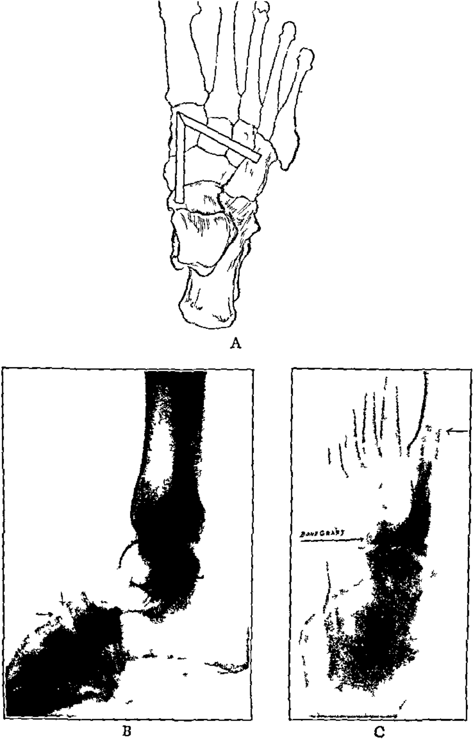


Fig 268 —*A* method of arthrodesis and support of the cuneiform cuboid scaphoid and astragalus bones by tibial bone grafts especially applicable in tuberculosis

B arrows indicate tuberculous lesion

C successful result after arthrodesis by method shown in *A* From Albee *Orthopedic and Reconstruction Surgery* Saunders

Resection of Os Calcis for Bone Malignancy and Other Conditions

A horseshoe incision is made beginning laterally at the base of the fifth metatarsal, encircling the heel and ending at the median surface below the internal malleolus. The resulting flap is reflected downward, and as much of the os calcis as is desirable removed with the gouge. Restoration may, in cases not secondarily infected, be made by means of bone graft. In the latter instance portions of the os calcis should be saved if possible, into which to insert the graft.

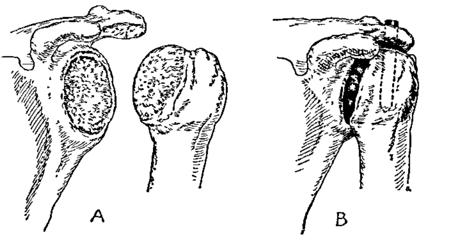


Fig 269—Technic for ankylosing the shoulder.
A, the cartilage from the glenoid fossa and acromion process, and contiguous surface of the head of the humerus is removed.
B, the humeral head is placed in the glenoid fossa and a bone graft peg inserted into it through the acromion process. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders

SHOULDER

1. Tuberculosis.—Operation to obviate the constant danger of infection of the lung, to eradicate the lesion and to relieve pain by securing complete ankylosis of the joint, is indicated. The operation of choice is erasion of joint surfaces followed by fixation of the joint by bone graft. Excision of the joint is an undesirable procedure in that the resulting deformity is great, with poor function.

Bone Graft Arthrodesis.—The incision is made from a point on the clavicle above the coracoid process, obliquely downward and outward along the anterior border of the deltoid. The deltoid is retracted outward, the pectoralis major with the cephalic vein inward. Divide the anterior border of the deltoid just below its attachment to the clavicle to

assist in retraction In the interval, there appear, from above downward, the pectoralis minor, coracobrachialis with the short head of the biceps, the anterior surface of the neck of the humerus and the tendon of the pectoralis major By pressing the finger on the humerus at the outer edge of the coracobrachialis and biceps, the bicipital groove of the humerus is felt, containing the long head of the biceps in its sheath, the sheath is slit and the biceps tendon retracted inward This partially opens the capsule of the shoulder joint the opening is further enlarged and the

A B

Fig 270—A tuberculosis of shoulder joint which has failed to respond to conservative therapy
B good result following arthrodesis by bone peg (BP) with technic shown in Fig 269

head of the humerus dislocated out of the wound which may be easily done by strong external rotation of the humerus

All cartilage is removed from the head of the humerus and the approximating surface of the acromion by a small hand saw, the single motor saw or osteotome, and from the glenoid cavity by a bone gouge or motor burr With an assistant holding the scapula in good position the head of the humerus is approximated to the glenoid cavity and acromion process, and the upper arm is elevated and pointed directly forward, with the arm rotated at the shoulder so that with the elbow flexed to a right angle and the thumb extended the tip of the thumb will come directly in front of the tip of the nose The joint is fixed in this position in the following manner

A hole is made with the small hip motor drill vertically downward through the acromion and through two-thirds of the diameter of the humeral head. A bone graft dowel peg previously fashioned by my dowel shaper of corresponding size from an autogenous tibial bone graft is driven through the acromion and head of the humerus. The periosteum is closed over the drill hole; sheaths, muscles and tendons are resutured; the skin wound is closed, and a plaster of paris shoulder spica is applied to the arm without changing its posture. This should be kept

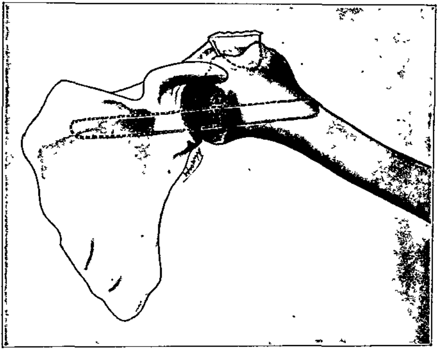


Fig. 271.—Brett's modification of author's bone graft fusion for tuberculosis of the shoulder From Brett, "A New Method of Arthrodesis of Shoulder Joint, Incorporating Control of the Scapula," *J. Bone & Joint Surg*, Oct., 1933, 15:973.

on for at least two months. The Albee fracture-orthopedic table with backrest is of great advantage in applying all such shoulder spicas (Fig. 270).

A. L. Brett prefers to "drive the tibial graft through the head, through the glenoid, and out through the spine of the scapula (Fig. 271). The acromion process which has been previously denuded of cartilage, is then broken down in the manner of a greenstick fracture so that it will present the broadest possible relation to the head of the humerus." [7]

[7] A. L. Brett, "A New Method of Arthrodesing the Shoulder Joint," *J. Bone & Joint Surg.*, Oct., 1933, 15:969.

2 Poliomyelitis —*Treatment* —In treatment, the first question is whether or not the paralysis is temporary or permanent, the second, whether, if permanent, it entails absolute inability to abduct the arm Lovett's statistics show that cases of complete, permanent paralysis are rare This coincides with my own experience and that of Steindler Since the chances of spontaneous recovery under conservative treatment and the use of the aeroplane splint and muscle education are good in many cases such treatment should always be given a fair trial before operative intervention is undertaken

Indications for Operation —Failure of the deltoid to present any signs of activity or life, no functional or electrodiagnostic response, degeneration of the muscle with atrophy and subluxation of the head of the humerus, permanent inability of abduction, failure to replace the deltoid action by substitutionary action (active contraction of the triceps, extending the elbow, or passive tension of the triceps, extending the elbow)

Two Types of Operative Treatment Are Possible —(1) Arthrodesis, (2) muscle or tendon transplantation I consider the first far superior If it is to be undertaken, one should first make certain that the patient has sufficient power in the muscles controlling the scapula to shrug his shoulders vigorously They are, fortunately, almost always uninvolved Sir Robert Jones advocated, as a preliminary to arthrodesis, intensive exercises for the elevators of the scapula For bilateral cases of paralysis, it may be well to arthrodese one shoulder and consider a muscle transplantation for the other, since there may be certain objections to fusing both shoulder joints

Arthrodesis is particularly useful if the muscles of the hand, elbow, and those uniting the scapula to the trunk are still active If the muscles controlling the elbow are also paralyzed, arthrodesis of both the shoulder and the elbow may, in rare cases, be advisable at one sitting

Age for Arthrodesis —Some authors, including Lange, maintain that one should wait until the fourteenth or eighteenth year, for reasons of growth, before doing an arthrodesis of the shoulder This delay I believe unnecessary if one uses the bone graft, and unwise because during the period of growth, if the flailness is left untreated, it will be a grave obstacle to the functional development of the entire arm I do not advise the operation until the child is eight years old because there is so large an amount of cartilage in the articulation, and because so much of the growth of the arm is at the shoulder joint But unless contraindicated, I recommend that it be done not later than this age

Angle of Fusion —One must decide at what angle the fusion should be accomplished and what the position should be in which the arm is held

in the plaster of paris cast following operation. Lange proposes 60; Vulpius the right-angle position; Vacchelli, who reported a series of cases ranging from five to fifteen years, also fixes the arm at right angles with the body. Steindler considers right angle abduction the safer procedure as one is apt to lose some of the abduction during the first few weeks of plaster fixation. Especially is this true in young children, where bony ankylosis cannot be relied upon.

For arthrodesis of shoulder following ununited fracture with bone loss, see Chapter VI.

ELBOW

Arthrodesis for Anterior Poliomyelitis.—*Flail Elbow.*—The forearm may be supported in several ways, *viz.,* by silk ligaments, fascial transplantation of flexor muscles, or a plastic operation on the skin. If all are ineffective, arthrodesis is the procedure of choice. However, the elbow joint is seldom rendered so utterly useless by infantile paralysis that arthrodesis is required to improve the function of the limb; in almost all cases enough power will be regained in the flexor muscles to enable the patient to control the joint, even if considerable weakness persists. If the flexor muscles of the elbow remain powerless, the muscles arising from the external condyle may have their origin shifted by operation to a higher point on the humerus, and thus obtain enough leverage to render them efficient as flexors. But in a paralytic patient with power absent also in the forearm, and only very weak power in the fingers, the resource of muscle transfer is not available; and it becomes necessary to adopt some other method to keep the elbow flexed and bring the feeble hand into a position where it will be of some use.

TECHNIC.—The joint is approached by one or two lateral incisions, 5 to 6 inches long, on either side of the olecranon; or the olecranon may be cut off and turned up from behind. The cartilage is removed by osteotome or gouge from the articulating surfaces of ulna, radius and humerus. The bone is fixed with sufficient flexion at the elbow to enable the hand to reach the mouth and the hand is placed in a position midway between pronation and supination. I prefer, as in all cases of arthrodesis, to employ a bone graft. With a motor drill 3/8 inch in diameter a hole is drilled through the ulna from its posterior aspect and into the condyle of the humerus. A tibial bone graft peg shaped with the motor dowel cutter is then inserted with the arm at right angles. If the shoulder and elbow are both flail, arthrodesis of each may be performed.

Campbell's Osteoperiosteal Graft for Tuberculosis.—A posterior incision 6 inches in length is made passing through the triceps muscle down to the humerus and extending below to the posterior surface of the ulna The lower third of the posterior surface of the humerus and the olecranon process of the ulna are exposed and bone shavings are chiseled from the cortex While this procedure is in progress an osteoperiosteal graft of suitable dimension is removed from the tibia the bony surface of which is placed in close proximity to the denuded surfaces of the humerus and olecranon process Close approximation is maintained by sutures or autogenous bone nails This procedure is very

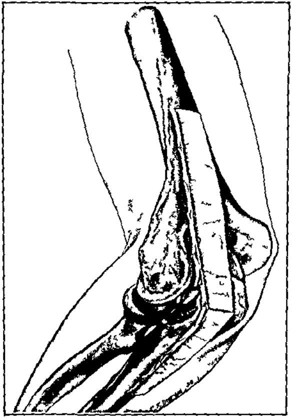


Fig 272—Fusion of elbow joint by osteoperiosteal graft From Campbell *Operative Orthopaedics* Mosby

rarely employed as extensive destruction is usually present when the process is first observed also osseous fusion may not be secured in sufficient time to prevent extension of the tuberculous process [8]

WRIST

Arthrodesis of the wrist is frequently indicated, in cases of flail wrist, in cases of ankylosis of the wrist, in faulty position and in arthritic con-

[8] Campbell *op cit*

ditions of the wrist joint. In the flail wrist the arthrodesis is indicated if control of the motions of the wrist joint cannot be secured by tendon transplantation and this is more frequently the case in the residual paralysis from poliomyelitis.

The suitable position of the wrist joint is hyperextension of 120 degrees. In this position, flexors and extensors of the wrist are balanced against each other and the dynamic conditions for the function of the flexors of the fingers are most favorable. Because of the fact that only exceptionally, for instance in peripheral lesions of the musculospiral, there is enough muscle material present to take care of both the stabilization of wrist and the movement of the fingers and thumbs, arthrodesis finds a wide application in paralytic drop wrist.

Fig 273—A case of drop wrist from anterior poliomyelitis and complete paralysis of the extensor muscles of the forearm. Any attempt to use the hand caused the unapposed muscles of the anterior forearm to acutely flex the hand, and therefore a complete loss of power to flex the fingers. From Albee, *Bone Graft Surgery*, Saunders.

In spastic paralysis, arthrodesis of the wrist effects a stable position in hyperextension, suitable for finger motion. This cannot, as a rule, be accomplished by tendon transplantation because it is most difficult in this type of paralysis to apportion properly the muscle balance between flexors and extensors. In the arthritic or in the posttraumatic arthritis of the wrist, obliteration of the wrist joint may be justified because of the permanent changes in the joint which make motion painful (adhesions) and in which, therefore, the obliteration of the wrist joint is as definitely indicated as in the posttraumatic arthritis of the ankle joint. It is of further significance for the indication that the arthrodesis does not prejudice simultaneous transplantation of the flexors of the wrist to the extensors of the fingers. This combination is a very practical one and the indications for it arise frequently. It is only necessary to pay proper attention to the

technic of the arthrodesis so as to prevent the formation of adhesions to the tendons as they cross from the volar to the dorsal side.

Liebolt presents a series of 44 cases from the New York Orthopedic Hospital in which the etiological indications for arthrodesis of the wrist

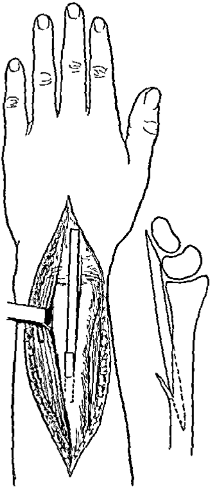


Fig 274.—The shape and position of the bone graft in its application to support a paralytic drop wrist in extension to restore the grasp of the flexors of the fingers This drawing does not indicate an intra-articular arthrodesis of the wrist joint which should always be done supplementing the graft From Albee, *Orthopedic and Reconstruction Surgery*, Saunders

joint were tuberculosis, rheumatoid arthritis, obstetrical paralysis, poliomyelitis, fracture dislocation, Volkmann's paralysis, gonorrheal arthritis and spastic paralysis.

1. **Arthrodesis of Flail Wrist.**—A linear incision is made on either the ulnar or radial side, and cartilage removed from the joint surfaces of

ulna, radius and carpus. The hand is put up in dorsiflexion, the most useful position for the flexors of the fingers. Additional assurance of bony ankylosis is attained if a bone graft is inlaid from the carpus to the radius or ulna, or bone pegs driven obliquely into the carpus from the ulna and radius. Figures 273 to 275 show a case of wrist drop and complete paralysis of the extensor muscles of the forearm, and the shape and position of the bone graft inserted into the radius and into the posterior surface of the os magnum, the grasp of the hand being almost completely restored by this procedure.

2. Tuberculosis.—*Arthrodesis by Bone Graft.*—The most complete fixation is afforded by a bone graft inlaid in the radius and os magnum

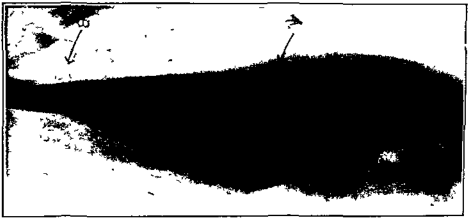


Fig. 275.—X-ray of case shown in Fig 273, after tibial bone graft had been inserted into radius onto posterior surface of the os magnum. *The grasp of the hand was almost completely restored by the mechanical support of the hand in extension.* From Albee, *Orthopedic and Reconstruction Surgery*, Saunders. (See Fig. 274)

or the radius and base of the third metacarpal bone without removal of bone. It has been employed successfully in cases that have persistently resisted conservative treatment. After a dorsal incision has been made and the carpus exposed, the periosteum is incised and elevated over the *distal extremity of the radius and os magnum or third metacarpal bone* (Fig. 276). With the twin motor saw a gutter is prepared, measurements of which are taken with the flexible probe and calipers and a bone graft of corresponding size removed from the tibia and inserted in the prepared bed. The graft is held in place by kangaroo tendon about the metacarpal bone and by the same material through drill holes in the radius or os magnum, if the latter has been used instead of the metacarpal bone. A supplemental tibial sliver graft may be placed in close approximation to the involved wrist at the side of the main graft. After

suturing periosteum and skin, the wound is dressed and the forearm, from finger-tips to elbow, immobilized in plaster of paris bandages for at least three months.

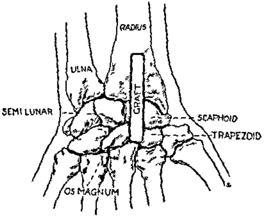


Fig 276.—Diagram showing details of method described in Fig 274

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CHAPTER IX

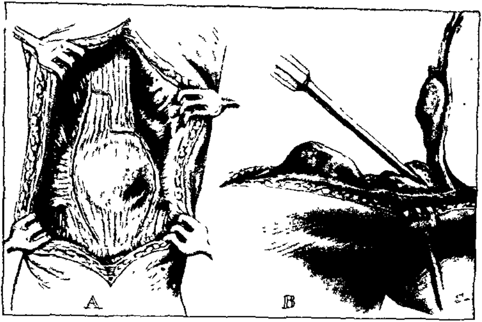
BONE BLOCK OPERATIONS

The technic of bone transplantation has found its most recent application in the stabilization of joints by means of bone block operations Campbell of Memphis first popularized this type of operation by fusing the patella to the tibia in a case of genu recurvatum Mayer has improved upon this technic by making use of a tibial bone graft to facilitate arthrodesis of the patella He has also applied this principle in treating recurrent dislocation of the temporomandibular joint At the shoulder the bone block has been found effective in preventing recurring dislocations of the humerus by Eden (1918) and Speed (1927) Putti s anterior bone block at the ankle for pes calcaneus and Campbell s posterior bone block for drop foot have secured brilliant results in these deformities Recently L Episcopo described a bone block operation at the hip joint with the purpose of creating an additional weight bearing surface for the relief of pain

GENU RECURVATUM

If due to deformity of the bones osteotomy of either tibia or femur as seems best may correct the distortion If due to other abnormalities it is essential to correct the primary cause In traumatic genu recurvatum the leg should be immobilized in flexion until healing occurs then massaged and properly supported by a brace with a stop joint to prevent hyperextension

Although a few degrees of hyperextension of the knee frequently give stability to a paralyzed joint which would otherwise be incapable of bearing the body weight genu recurvatum of 250 degrees or more in such cases constitutes a serious handicap to locomotion Persistent de



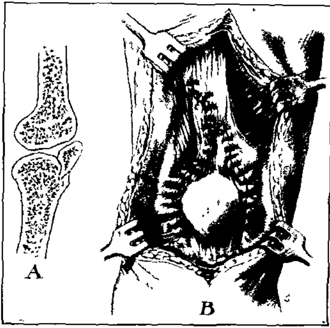


Fig. 277.—Above, Campbell's operation for genu recurvatum. *A*, quadriceps lengthened and patella and ligamentum patellae freed. *B*, distal end of patella freed of soft tissue attachments and denuded to spongy bone Osseous flap pried forward from anterior aspect of tibial condyle

Below, *A*, patella inserted into cleft in tibia. *B*, closure of wounds so as to lengthen quadriceps tendon. From Campbell, *Operative Orthopaedics*, Mosby.

formity of this type calls for arthrodesis of the joint, with or without reinforcement by bone graft Or, one may use supracondylar osteotomy of the femur followed by rotation of the lower segment to overcome the deformity, performed synchronously with tendon transplantation In mild cases in which the hamstring muscles are strong and the recurvatum is due to paralysis of the quadriceps, excellent results are obtained by transplanting the biceps and semitendinosus to the patella and reefing the posterior capsule of the joint

Campbell in 1918 devised an operation, whereby he endeavored to correct this deformity by implanting the patella into the upper end of the tibia (Fig 277)

Campbell s Fusion of Patella to Tibia.—A longitudinal or transverse incision is made over the insertion of the patellar tendon The attachment of the tendon is removed and a shallow depression made on the upper surface of the tibia The lower third or half of the patella is denuded of cartilage and tend nous attachments and this portion of the bone placed in contact with the denuded area of the tibia This position is maintained by suturing the remainder of the patellar tendon to the periosteum of the tibia and to the capsule of the knee joint A stop joint is thus formed blocking hyperextension The wound is closed and the leg immobilized in a cast the knee being slightly flexed for a period of three or four months Walking is then permitted in a brace which allows flexion but prevents hyperextension [1]

Mayer found two drawbacks in Campbell s technic

First, difficulty in freeing the patella sufficiently to permit its implantation, and second, the relatively small size of the patella which failed to give a large enough bone block To create an adequate bone block so attached to the tibia as to correspond to the olecranon process of the ulna, he devised (1930) the following technic

Mayer s Operation—A midl ne incision is made beginning three inches above the patella extending downward to the tuberosity of the tibia or if the bone graft is to be removed from the tibia the incision is extended three inches further The skin is dissected back sufficiently to expose the lateral recesses of the jo nt An inverted V shaped incision is then made through the quadriceps tendon running downward through the joint capsule on each side of the patella to within an inch of the lateral ligaments (Fig 278) By retracting the patella downward this incision gives free access to the joint To give a better exposure of the upper end of the tibia the ligamentum mucosum is div ded and part of the retropatellar fat pad is excised A chisel (1½ inch) is then driven vertically downward into the tibia for a distance of one inch The cutting edge of the chisel is placed at right angles to the anteroposterior axis of the knee just between the attachment of the anterior crucial l gament and the internal meniscus That portion of the t b a lying anterior to the chisel is pried gently forward so as to make room for a bone graft This is taken either from the femur or the tibia. It should measure

[1] Willis C Campbell *A Textbook of Orthopedic Surgery* W B Saunders Co., Philadelphia 1930

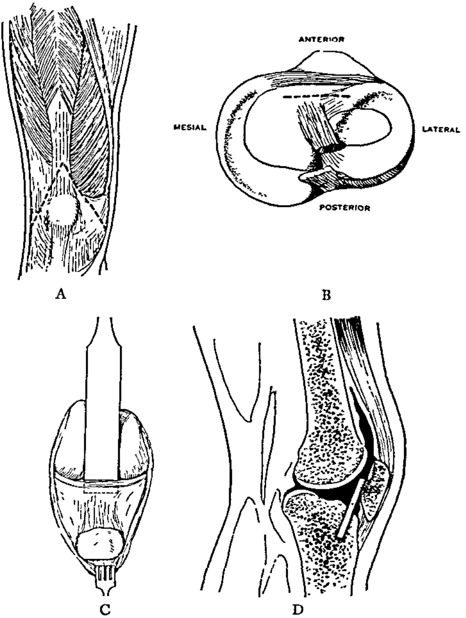


Fig 278.—*A*, anterior view of the knee showing the line of incision through the quadriceps tendon and the capsule of the joint.

B, view of the articular surface of the tibia showing the line of incision into the tibia. This lies directly in front of the attachment of the anterior crucial ligament to the spine of the tibia, and just posterior to the attachment of the internal meniscus The chisel nicks the external meniscus near its attachment but does not completely sever it

C, the patella and patella tendon are retracted downward and the chisel, inserted along the line in Fig. B, is driven vertically downward into the tibia for about one inch.

D, sagittal section through the knee joint after the implantation of the bone graft. The deep surface of the patella has been denuded of cartilage and makes contact with the rough surface of the graft The smooth surface of the graft faces the femur. From Mayer, "Operation for Paralytic Genu Recurvatum," *J. Bone & Joint Surg.*, Oct., 1930, 12, 4:846.

approximately two and a quarter inches long one and a quarter inches wide and three sixteenths of an inch thick The end to be inserted into the tibia should be a trifle narrower and should be beveled to permit easier insertion The femur is more accessible than the tibia since its lower end covered with cartilage lies exposed in the wound The tibial graft however though requiring a prolongation of the original incision is much more easily driven into the cleft made by the chisel The graft its smooth surface facing the joint is driven downward into the tibia leaving about one inch projecting from the upper surface of the tibia The patella is next denuded of cartilage It is found that the raw surface of the patella makes good contact with the raw surface of the graft thus insuring a solid union between them The incision into the joint and quadriceps tendon is closed by continuous chromic stitches the skin with a continuous fine plain gut Postoperatively the knee is flexed to 135 degrees for four weeks to guard against overcorrection leading to flexion contracture"

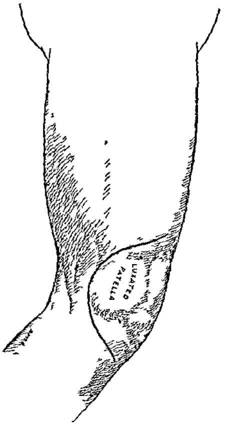


Fig 279—Luxated patella outward From Albee *Orthopedic and Reconstruction Surgery* Saunders

HABITUAL DISLOCATION OR SLIPPING OF PATELLA

The treatment for habitual dislocation or slipping patella is essentially surgical, and the simple procedure of transferring the insertion of the patellar tendon to the inner side at the mid line of the tibia will prevent dislocation providing the intercondylar groove is intact If the outer portion of this groove has been flattened down, the patella may still slip and in this event the deepening of the groove is necessary

Operative measures providing bony obstruction to redislocation have been far more successful than those which rely on correction by soft tissue operations Grafted or reefed soft tissue whether ligament or fascia will not withstand constant stretching or strain, and will gradually yield The soft tissues of the front of the knee, however much altered by reefing will slowly come back to the same condition as before operation Repeated flexion of the knee constantly stretches them

[2] Leo Mayer J *Bone & Joint Surg.*, 1930 12 845

over the unaltered bony contour of the anterior part of the knee joint, precisely as a rubber glove stretches over a hand.

Surgical interference of many types has been practised:

(1) Raising the external condyle of the femur and insertion of a bone graft wedge (Albee); (2) opening the joint, gouging out a space on the inner condyle to receive the patella, and suturing it in place (Championniere, Murphy); (3) tibial surface gouged out to fit the condyles (Reiner); (4) simple removal of the patella (Fowler); (5) hypertrophy of the condyle produced by repeated blows of a mallet (Ridlon and Thomas); (6) plastic operations on the capsule (Wright, LeDentu and Chevrier); (7) osteotomy, with folding of the inner part of the capsule and enlargement of the trochlear surface by *chiseling* (Adelbert); (8) chiseling of the trochlea and excision of the inner part of the

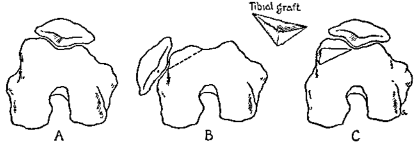


Fig 280—*A* indicates the normal size and anterior prominence of the external femoral condyle *B* indicates the flattened external condyle with a consequent luxation of the patella outward *C* indicates anterior lifting of the condyle to block the recurrence of the luxation of the patella with the wedge graft (dark area) in position The graft is usually held by a ligature of kangaroo tendon placed in drill holes in it and the split portions of femur anterior and posterior to it. From Albee, *Orthopedic and Reconstruction Surgery*, Saunders.

capsule (Pollard); (9) cutting away the insertion of the vastus externus from the patella and transplantation of the insertion of the ligamentum patellae further inward on the tibia (Casati).

Normally there is an anatomical groove on the anterior surface of the lower end of the femur with a larger shoulder on the outer side which serves to prevent dislocation. In cases of habitual dislocation, this external shoulder is always flattened. In certain cases, not only is the shoulder flattened, but the groove is entirely filled up with a dome of bone. It seems certain that this change of bony contour is the principal cause of the recurrence of the dislocation. In all instances when an abnormal condition is due to an anatomic defect, it is best, if possible, to follow Nature and restore the anatomy to as nearly normal as possible.

Therefore, inspired by the numerous failures following other methods, I have devised a technic to lift the anterior portion of the external con-

dyle This technic is simple and can be done in 10 or 15 minutes —more quickly than some of the soft tissue operations which do not restore the normal anatomic relations and contours and are extremely likely to be followed by recurrence

Albee Bone Graft Wedge for Habitual Dislocation of the Patella — A semilunar skin incision is made at the outer border of the patella, suf

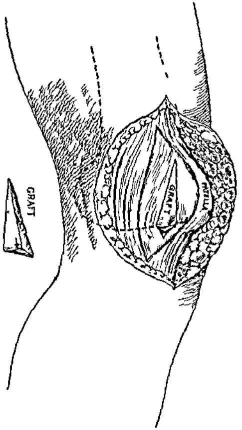


Fig 281 —Author s operation for outward dislocation of the patella showing shape of graft in position lifting anterior portion of external condyle to block the recurrence of the dislocation From Albee *Orthopedic and Reconstruction Surgery* Saunders

ficiently long to reach below the tibial tubercle and to a point above the external condyle (Fig 279) Avoiding undue disturbance of the underlying joint structures the external condyle is penetrated with a broad thin osteotome on its external surface making a bone incision from 1½ to 2 inches long *and situated about one half to three quarters of an inch* below the anterior articular surface of the femur and nearly in line with its long axis This bone incision allows the anterior surface of the external condyle *to be elevated to a plane above the internal condyle by producing*

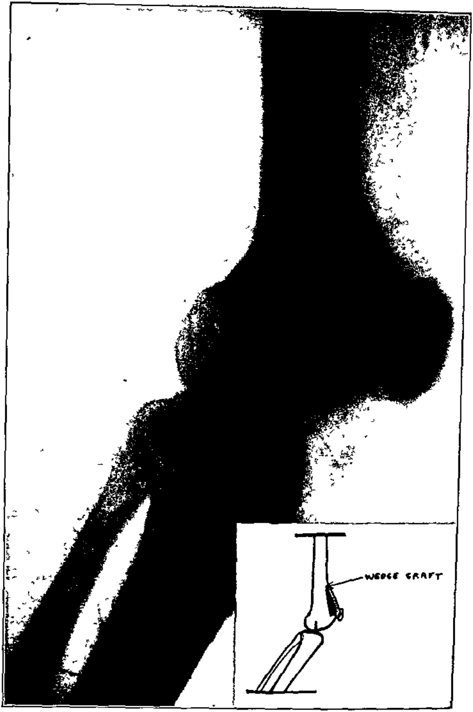


Fig 282—Roentgenogram of case of recurrent subluxation of the patella—shows tibial wedge graft in position under the elevated femoral condyle (See Fig. 281). From Albee, *Orthopedic and Reconstruction Surgery,* Saunders.

a greenstick fracture near the intercondylar groove, the object being to place a permanent and rigid obstacle in the way of outward displacement of the patella (Figs 280-281)

When the anterior segment of the external condyle has been obliquely elevated to a sufficient degree to secure the desired obstructing effect, the width of the bone gap thus formed is measured, and a section of bone sufficiently large to fill this cuneiform opening is removed from the crest of the tibia through the lower portion of the original skin incision, extended below the tubercle for this purpose This bone graft wedge can

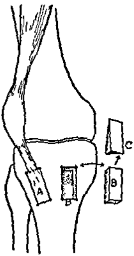


Fig 283

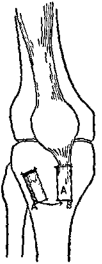


Fig 284

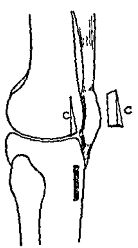


Fig 285

Fig 283—Method used for extreme outward dislocation of patella Insertion of ligamentum patellae transferred medially from *A* to *B* Portion of bone removed at *B* used to make double wedge graft *C* for elevation of condyle (Fig 285)

Fig 284—Patella in correct position

Fig 285—Rectangle of bone removed from *B*, shaped to double wedge *C* and used to elevate outer condyle as shown in Fig 280

be easily and quickly procured by the motor saw Before the graft is removed, it is drilled obliquely in one or two places with a motor drill so that it may be pegged to the under portion of the external condyle after it has been put in position Dowel pins made from an additional portion of the bone removed from the crest of the tibia at the time the graft is obtained, and rounded by the motor lathe to fit the drill holes in the graft, are driven into place

The cancellous structure of the condyle is easily penetrated by the bone graft pins, but if any difficulty is encountered, the motor drill can again be inserted into the holes already made in the graft and these prolonged into the external condyle The ligaments and tendinous expan-

sions are sutured over the graft by kangaroo tendon, thus securely holding the elevated portion of the condyle. The leg from toes to groin is encased in a plaster of paris splint in which it is allowed to remain for three weeks; at the end of this time passive motion and massage are begun.

The advantages of this procedure are that with no sacrifice of joint cartilage, a minimal amount of joint injury is produced at the time of operation, thereby greatly lessening the dangers of limitation of motion and the formation of adhesions, and that the permanent blocking of any further tendency to displacement of the patella is effected by the actual elevation of the external condyle or an actual restoration of the normal anatomical conditions. The soft parts are not interfered with. The only further suggestion in the case of extremely lax and stretched internal capsular ligaments is their plication; this, however, is usually unnecessary, for if the external condyl is propped well forward, all requirements are fulfilled (Fig. 282).

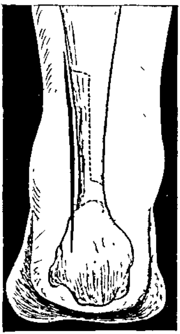
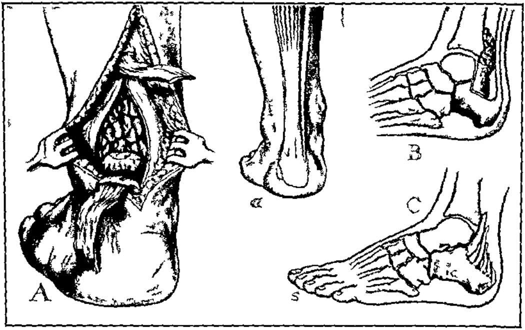


Fig 286.—Z-shaped incision for lengthening tendo achillis From Campbell, *Operative Orthopedics*, Mosby, 1939.

Extreme degrees of outward dislocation of the patella may result following faulty technic employed in the transplantation of the biceps femoris into the patella for paralysis of the quadriceps. The author has found it necessary to combine elevation of the outer condyle by bone graft wedge with a plastic procedure on the ligamentum patellae in order to prevent dislocation of the patella from the front of the joint during knee flexion. The insertion of the ligamentum patellae plus a rectangular bone are excised with a twin motor saw and transposed to the anteromesial surface of the tibia at *B* (Figs. 283-284), where a corresponding rectangle has been removed. The twin saw used as a caliper assures an accurate fit. The rectangular bone removed from *B* is shaped to a double wedge *C* (Fig. 285) and used as described previously for the elevation of the outer condyle. (See page 367.)

ANKLE JOINT

Campbell's Posterior Bone Block for the Correction of Talipes Equinus.—Campbell transplants a mass of spongy bone into the upper



Figs 287 288 —Campbell's bone block for paralytic equinus (drop foot) *a* line of incision *Posterior surface of joint exposed by retraction or Z plastic division of tendo achillis*
A operation completed showing large block of bone with numerous small chips pyramided above
B relation of block to subastragalar and ankle joints and to posterior surface of tibia
C *bone block alone performed by reflections of bone forward and upward from superior* surface of os calcis From Campbell *Operative Orthopaedics* Mosby

Fig. 289—End result eighteen years after bone block for paralytic drop foot From Campbell *Operative Orthopaedics* Mosby

surface of the os calcis in close proximity to the ankle joint. This new bone fuses with the os calcis, and forms a process which impinges upon the posterior surface of the tibia and prevents plantar flexion. The procedure is usually combined with triple arthrodesis and thus has the advantage of stabilizing anteroposterior as well as lateral motion, and also conserving the rocker motion of the ankle joint. The extent of the fusion varies according to the demands of the case; sometimes the midtarsus, the astragaloscaphoid and calcaneocuboid must be fused; sometimes the *calcaneoastragaloid, calcaneocuboid and astragaloscaphoid articulations.*

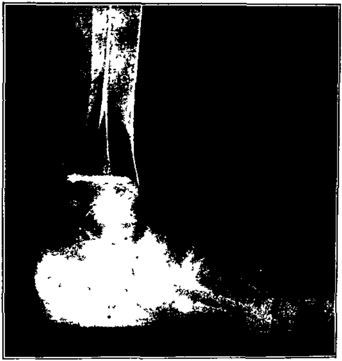


Fig. 290—Illustration showing Miltner's bone block of the ankle for talipes equinus. Observe how the displaced fragment of fibula, held securely to the posterior surface of the tibia by means of a beef bone screw, acts as a block at *a* against the equinus position of the os calcis. From Leo Miltner, "Bone Block of the Ankle," *Nat. M. J. China,* 1931, 17:313.

The skin incision is made over the Achilles tendon, if this structure is contracted; otherwise to the outer or inner side, as is convenient. It should extend from the superior aspect of the tuberosity of the os calcis upward for 3 or 4 inches in a straight line. If the Achilles tendon is contracted, a severance is made by the Z-shaped plastic method.

A straight incision is next made in the midline to the posterior surface of the ankle joint, retracting inward the tendon of the flexor longus hallucis. With a heavy periosteal elevator, a pyramidal space is cleared, exposing the posterior surface of the tibia, ankle joint, subastragalar joint, and superior surface of the os calcis. The foot is dorsiflexed, bringing into view the posterior extremity of the astragalus for ½ to ¾ inch. This por-

tion of the astragalus is removed and a wedge-shaped cavity excavated on the os calcis below the posterior extremity of the astragalus and the posterior portion of the articular surface of the tibia Bone may be transplanted from any portion of the skeleton As it is usually necessary to enter the forefoot for the purpose of stabilizat on by arthrodesis bone is excised from the forefoot it is denuded of cartilage and a large piece about ½ inch in diameter is selected and placed in the cavity prepared on the superior surface of the os calcis about which small particles are arranged in a pyramid shape

The cartilage removed is placed in mosaic fashion to cover the posterior, inner and

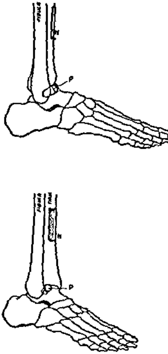


FIG. 291

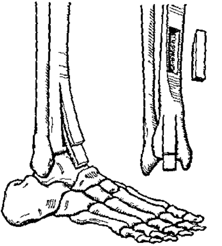


FIG 292

Fig 291 —*Putti s method of inserting tibial* bone graft *in* bone block *operation for pes* calcaneus

Fig 292 —Diagram of author s modificat on of Putti s anterior bone block for pes calcaneus The bone graft *is placed in a mortise in the t b a above the ankle and imp nges against the* head of the astragalus (Fig 293) Reproduced by permission of Vittorio Putti

outer aspects of the pyramid and to prevent adhesion to surrounding structures This step however is by no means essential as the results are as good when bone is obtained elsewhere without cartilage The soft tissues are sutured snugly to retain the transplants *in situ* the Achilles tendon is un ted if severance had been required and the fascia and skin are closed The foot is then held by a plaster cast at an angle of 90 degrees with the leg The techn que may be modified when the forefoot is stable by turning forward the upper third of the os calcis In performing a triple arthrodesis it is also possible to transfer particles of bone from the midtarsal region through the subastragalar joint to the superior surface of the os calcis but the block cannot be so accurately placed as when the posterior incision is employed [3]

[3] Willis C Campbell *Textbook of Orthopedic Surgery* W B Saunders Philadelphia 1930.

This is a mechanically sound and trustworthy operation, forming a true bone block by use of the bone graft. It should be employed not only for simple drop foot, but for partial drop foot (with loss of from 50 to 75 per cent of normal power of dorsiflexion), rigid equinus, equinovarus, equinovalgus (certain cases) and flail foot (as an addition to other procedures). Campbell also uses it as an adjunct to various combinations of tendon transference and in spastic paralysis with overactive heel cord.

Fig 293—Roentgenogram of ankle following operation with technic illustrated in Fig 292. Second graft for astragalonavicular arthrodesis.

Miltner Bone Block for Talipes Equinus.—A modified Kocher incision is used (Fig. 290). The lower one-fourth of the fibula is exposed. The peroneal tendons are divided and retracted. The posterior longitudinal portion of the fibula is stripped free from muscle and fascial insertions in its lower one-fourth. Care is taken to preserve the insertion of the external deltoid ligament of the ankle, which remains attached to the anterior longitudinal portion of the fibula.

The posterior surface of the os calcis (in front of the insertion of the tendo Achilles) and the posterior surface of the lower end of the tibia is exposed. With an electric saw the fibula is cut longitudinally to about four inches above the external malleolus.

The lower posterior surface of the tibia is then roughened with a chisel. This area, denuded of periosteum along with a thin layer of cortex, is prepared to receive a similar roughened area of the fibula.

The posterior portion of the fibula which is separated is then fractured at its upper end The lower end of this fragment of fibula is displaced so that it acts as a posterior bone block against the os calcis. This piece of fibula is then held securely to the posterior surface of the tibia by means of a beef bone screw. The peroneal tendons are resutured and the wound closed.

At this stage, or even before the displacement of the piece of fibula, the subastragaloid arthrodesis may be done. In doing the subastragaloid arthrodesis the thickness of the layer of bone removed determines the extent to which the os calcis may rise without impinging against the tip of the block. A plaster of paris cast is applied for a period varying from three to four months, depending upon the rapidity of healing of the bone as demonstrated by roentgenograms.[4]

[4] Leo J. Miltner, *Nat. M. J. China*, 1931, 17:313.

Putti's Anterior Bone Block for Talipes Calcaneus.—(Fig. 291).—An oblique incision over the external aspect of the ankle exposes the upper ankle joint. The tendons, vessels and anterior tibial nerve are retracted inward, until the upper surface of the body of the astragalus is in full view. The foot is then tilted downward, so as to bring the posterior portion of the astragalus into a position which would correspond to about 110 degrees of equinus. A thin chisel is then driven vertically into the body of the astragalus, splitting it for the reception of a tibial bone graft measuring in width a trifle less than the astragalus, having the thickness

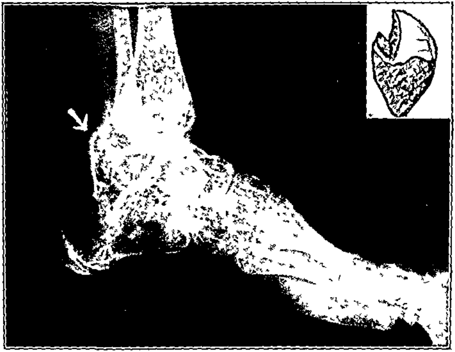


Fig 294—Inclan's bone block technic. Courtesy of Dr Alberto Inclan

of the tibial cortex and long enough to project ⅛ inch beyond the astragalus. This graft, healing firmly with the astragalus, effectively blocks excessive dorsiflexion and at the same time permits sufficient motion for a good stride.

Putti's procedure does not attempt correction of the cavus, nor does it permit the posterior displacement of the os calcis which is so important a feature of Whitman's operation. To accomplish this double purpose, Mayer has modified the Hoke stabilization Instead of shortening the neck of the astragalus as Hoke does, Mayer resects enough of the head to permit generous posterior displacement of the os calcis after division

of all the astragalocalcaneal ligaments. The additional cuneiform resection of bone at the calcaneocuboid joint, together with the thorough division of both the long and short plantar ligaments and of the plantar fascia, permits correction of the cavus.

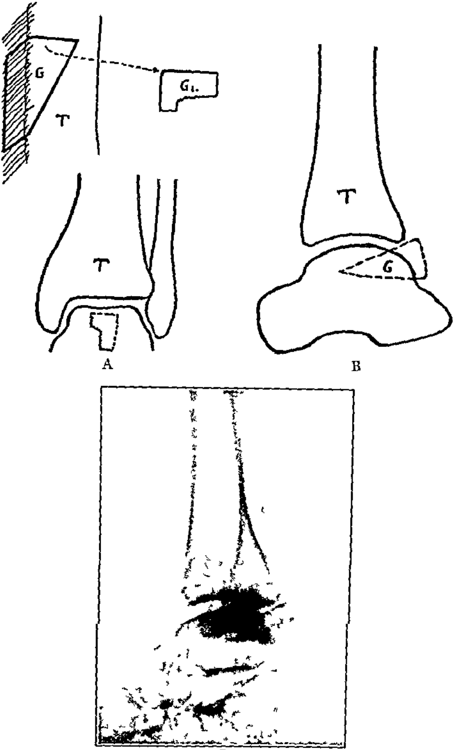
I have found in severe cases of calcaneus where the foot swings markedly outward as the forefoot dorsiflexes, that a strong tibial graft ¾ to 1 inch long, approximately ⅝ of an inch wide, and full thickness of the cortex, placed in a mortise on the anterior and outer surface of the tibia just above the insertion of the ankle joint capsule, gives better bone block stability than when similarly placed in the astragalus according to Putti's technic. In this instance the superior and outer surface of the neck of the astragalus impinges against the lower end of the graft (Figs. 292-293).

Inclán, of Havana, has devised an operation to stabilize the foot in paralytic calcaneus. He excises the head of the astragalus, models it into a hook-shaped graft and implants it posteriorly. This is done in conjunction with a triple arthrodesis (see Fig. 294).

Dilger's Anterior or Posterior Bone Block of the Ankle for Paralytic Equinus or Calcaneus.—*Technic: Posterior Bone Block.*—An incision is made over the tendo achillis, which is divided by a Z-shaped tenotomy and reflected. After clearing away the loose areolar tissue with a periosteal elevator, the posterior portion of the capsule of the ankle joint is brought into view. A small vertical incision is made into this, exposing the posterosuperior surface of the astragalus, and the posteroinferior border of the tibia. With a ¼ inch drill, a drill hole is made into the astragalus at the exact spot where it is desired to check plantar flexion. This drill hole is then enlarged laterally and distally by means of a fraise, so that it has the shape of an inverted L. A second small incision is made over the crest of the tibia, which is exposed by stripping off the muscle from its medial surface.

A wedge of bone is then removed by means of the Albee saw, an oblique and a transverse saw cut being made in the anterior surface, and a longitudinal cut in the lateral surface of the tibia. This provides a very strong wedge graft, consisting of the whole crest of the tibia. This wedge is driven firmly into the astragalus, and seated by blows of a mallet upon the Albee bone drift (similar to an enlarged nail-set) (Fig. 295 *A* & *B*). The tendo achillis is sutured in the usual manner, with the required amount of lengthening.

Anterior Bone Block.—The operation is done precisely as above, except that the first incision is made anterior to the ankle joint, and the extensor tendons are retracted, exposing the anterior portion of the capsule of the ankle joint. After either operation, a plaster cast is applied



C

Fig 295.—*A*, diagram showing Dilger's method of removal of wedge graft from tibia *G* indicates wedge graft *G* cross-section at thick end

B implanting wedge graft Graft may be placed either anteriorly or posteriorly

C, x ray result two months postoperatively From Dilger, "A New Operation for Producing Anterior or Posterior Bone Block of the Ankle," *Am. J. Surg.* Feb. [illegible]

for three or four weeks, unless an associated arthrodesis should require longer immobilization.

SHOULDER JOINT

Recurrent Dislocation.—*Stabilizing Operation.*—Although the author prefers the Nicoladoni operation in treating habitual dislocation of the shoulder, yet the bone block operation, first published by Eden, and later worked out independently with a slightly different approach by Speed, has much to commend it. Should the graft remain viable and form a heavy spur of bone projecting from the neck of the scapula, it must surely arrest the wandering humeral head. It is somewhat analogous to the spur purposely formed on the superior surface of the os calcis, in the Campbell operation, in which neither absorption nor irritation follows.

Eden's Method.—An oblique incision is made over the anterior surface of the shoulder along the line of junction of the deltoid and pectoralis major and the front of the joint is exposed by retraction of these muscles. The lower portion of the subscapularis muscle is separated from the front of the capsule and tracted upward, exposing the baggy portion of the capsule. The capsule is incised and the anteroinferior margin of the glenoid located. A ¾ inch incision is made in the capsule at its insertion and a pocket is made by separation of the periosteum from the neck and first portion of the body by means of a chisel. A graft approximately 2 inches long by ¾ inch wide is cut from the upper part of the anteromesial surface of the tibia and one end is tapered with bone-cutting forceps. A hole is bored through the graft 1 centimeter from the broad end and a catgut suture passed through it. The graft is then inserted into the pocket and stitched to the capsule by means of the catgut suture. This allows the end of the graft to project slightly beyond the lower margin of the glenoid. The capsule is then plicated with interrupted catgut sutures and the wound closed. The arm is bandaged to the side for three weeks and then carried in a sling for two weeks, after which motion is gradually begun.[5]

Eden's first operation was performed in 1917. In 1924, Oudard combined a plastic operation on the subscapularis tendon with reconstruction of the coracoid. The tendon was shortened by doubling. The tip of the coracoid was sawed off to lower the coracobrachialis and pectoralis minor. A piece of bone 3 to 4 cm. long was then grafted into the coracoid between the base and sawed-off tip. (See Fig. 296.)

Speed's Technic (1925).—In muscular men an incision is made from just below the coracoid process straight down about 4 inches through the skin, superficial fat, and fascia. The edge of the pectoralis major muscle is then identified at the lower angle of the incision. By blunt dissection the left index finger is pushed up under the muscle until its upper border is reached and at the point of junction with the deltoid, the finger is

[5] R. Eden, *Deutsche Ztschr. f. Chir.*, 1918, 144:269-280.

hooked through and the muscle is cut transversely across its fibers about 1½ inches from the tend nous insertion into the humerus

Retraction of the muscle ends exposes the axillary contents The nerves and blood vessels are gently held out of the way and the edge of the glenoid fossa is palpated deep in the wound above the axilla By blunt d ssection all important structures being avoided this glenoid edge is brought into view The capsule of the shoulder joint is usually not opened

In women the approach through the deltopectoral junction across the shoulder usually affords sufficient space upon retraction A broad drill point or chisel is then inserted into the scapula just anterior to the glenoid edge near its lower margin A hole is drilled about 1 inch deep diagonally into the neck of the scapula Into this is inserted a bone transplant removed from the anterior surface of the tibia The transplant is driven home and about ¾ of an inch is left projecting anteriorly and obliquely across the lower anterior marg n of the shoulder jo nt This in no way interferes with normal range of

Fig 296—Bone transplant (*A*) under edge of glenoid one year after operat on by Eden s method From Speed Recurrent Anter or Dislocation at the Shoulder *Surg Gynec & Obst* April 1927 44 474. By courtesy of *Surgery Gynecology and Obstetrics*

shoulder joint motion but it does prevent the head of the humerus from sl pp ng out forward into anterior and habitual dislocation The anterior capsule may be exposed and sutured if it is considered necessary as an extra precaution Any active hemorrhage is checked The great pectoral muscle is sutured by mattress stitches of heavy catgut and an accurate re approximation thus made The pectoral fascia is then sutured by a runn ng stitch of lighter catgut the skin is closed with black silk and a capillary drain left near but not exactly at the lower angle of the wound The arm is held in a sling close to the chest after the wound is dressed

Within a week the forearm is removed daily from the sling for elbow jo nt motions After 12 to 14 days active abduction of the arm is requested and after 3 weeks no arm support of any kind is used abduction of the arm being encouraged Within 4 to 5 weeks after operation the arm can be actively abducted beyond a right angle and full action of the pectoralis major returns Ult mately complete elevation of the arm becomes pos sible and no degree of hyperabduction leads to another dislocation (Fig 296)[6]

[6] Kellogg Speed *Surg Gynec & Obst* April 1927 468 477

The anterior approach used by Speed offers a very clear view of the shoulder joint region. The bone transplant need not be so large as that used by Eden, and its fixation is secure in the drilled or chiseled hole along the neck of the scapula.

BONE BLOCK FOR RECURRENT DISLOCATION OF JAW

Mayer has devised a bone block operation for recurrent dislocation of the jaw. He believes that in the temporomandibular joint, dislocation can best be prevented by the bone block method so effective in overcoming genu recurvatum and drop foot—since this method would actually correct the pathology—namely, the excessive shallowness of the temporal fossa.

The operation is best performed under local anesthesia. It is done through a two-inch horizontal incision running along the zygomatic process almost to the external auditory meatus, then gently upward and backward over the base of the pinna of the ear. This incision was at first believed to be original, but it had already been used by Burdick, though not published by him. It has the advantage over the short horizontal and angular incisions of Murphy, Henderson, and others in that it gives an unusually good approach to the joint. This is done by turning the pinna of the ear downward, thus exposing the zygomatic process from its base posteriorly to a point anterior to the temporomandibular joint (Fig. 297). This approach has one advantage; it necessitates the division of the superficial temporal vessels, which run vertically just anterior to the ear, and also necessitates strong retraction of the superficial temporal nerve, a branch of the fifth cranial nerve supplying sensation to the lateral portion of the forehead. Even though the nerve is cut or injured, however, the sensory loss is so slight as to be of little practical significance. About one inch of the zygomatic process is cut away with the motor saw or with any suitable bone-cutting instrument. This at once exposes the temporomandibular joint. The capsule of the joint is divided by a transverse incision or by a transverse combined with a vertical. It is then possible to study the exact pathology of the particular case. The patient is asked to open the mouth and during this act the motions of the condyle and of the inter-articular cartilage can be accurately observed. In one of the four cases operated upon, the pathology was due entirely to a loose cartilage and as soon as this had been removed, the snapping stopped. In the other three cases, despite preliminary removal of the meniscus, the condyle could be seen slipping forward over the eminentia articularis as the mouth was opened. To prevent the slipping from occur-

ring the resected portion of the zygomatic process is utilized as a bone graft and inserted just anterior to the eminentia articularis A vertical groove exactly corresponding in size to the width of the bone graft is cut in the temporal bone Its depth should correspond to the thickness of the graft (usually about ⅛ of an inch) The groove is about one half an inch long, permitting one half of the graft to project downward In cutting the groove, the edges should be made slightly oblique so that the graft will be firmly mortised in place when driven into position No fixation sutures are necessary When the graft is in place, the patient is

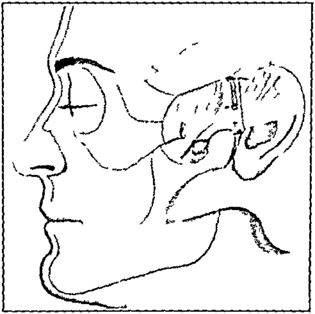


Fig 297.—Mayer's bone block operation for recurrent dislocation of the jaw The bone graft has been mortised into the temporal bone just anterior to the eminentia articularis The projecting portion of the bone graft has been shaded From Mayer Recurrent Dislocation of the Jaw *J Bone & Joint Surg* Oct 1933 15 4 89

again allowed to open the mouth and if the technic has been correct, a slipping will be prevented by the bone graft The operation is then completed by a careful suture of the capsule of the joint closure of the fascia and of the skin That portion of the zygomatic process which was resected for the exposure of the joint is usually just the right size for the bone block It is unnecessary to replace the resected zygoma since this defect is not noticeable either in the appearance of the face or the function of the jaw Great care must be taken in this operation, as in all operations on the temporomandibular joint, not to injure the branches of the facial nerves which cross upward over the anterior portion of

the zygomatic process. Morris has pointed out that, since these branches are running deep to the fascia, injury can be made less probable by thorough retraction of the temporal fascia. At the conclusion of the operation a plaster of paris helmet, completely encasing the head, is applied so as to prevent motion of the jaw until the graft has healed in place. Thus far, immobilization of from four to six weeks has proved adequate. The patients are given a liquid diet for the first ten days. It has not been necessary to remove teeth for feeding, since the plaster, though snug, permits the passage of a glass tube between the teeth. After ten days the patients are able to open the teeth sufficiently to eat soft food.

Thus far the bone block method has been used in three cases. In all three, the condition of slipping caused marked disability not alleviated by careful nonoperative treatment. In all three cases the bone block method has been successful.

BONE BLOCK FOR PAINFUL HIPS

L'Episcopo's operation represents an attempt to conserve motion in arthritis of the hip joint and relieve pain. It has been performed following slipped epiphysis, congenital dislocation, tuberculosis and hypertrophic arthritis. He states the rationale is difficult to explain, but it seems that the bone block apparently takes some of the weight in walking and thus relieves the weight bearing joint surfaces.

TECHNIC OF OPERATION

The hip area and the side of the ilium are exposed by a modified Smith-Petersen incision, bringing the upper arm of the incision well back along the crest of the ilium to expose the crest and the upper portion of the side of the ilium to permit the removal of a good-sized graft. This graft is taken in one of two directions, depending on the individual case. If there is no protrusion at the outer junction of the head and the acetabulum, a straight graft is used to stretch across the joint between the ilium and the trochanteric fossa or the greater trochanter. In some cases there is a mass of bone at the acetabulofemoral junction, so that a straight graft will not reach between these points. In that case, a curved graft is necessary. The straight graft is taken vertically on the side of the ilium, including half the crest and the outer table of the ilium, and is sufficiently long to reach between the points of contact which have been previously determined. The graft should be about one and a half

inches wide If the curved graft is necessary, it is taken along the natural curve of the ilium, starting just behind the anterosuperior spine and going backward until the desired length can be removed When measuring for the length of the graft, the surgeon should adduct the thigh, so that after the upper end of the graft is placed in a slot on the side of the ilium the lower end is jammed tightly against the trochanter or the trochanteric fossa, as the thigh is abducted to the straight or neutral position One must be sure not to place it in the slightest abduction As the thigh is brought from the adduction to the neutral position, the graft is firmly pushed into the ilium No sutures are necessary to hold the graft A hip spica is then applied from the nipple line to the ankle This is changed to a short spica after six or eight weeks, and the patient is allowed to walk with crutches Complete weight bearing is permitted as soon as roentgenographic examination shows union of the graft to the ilium, which is usually seen in from ten to twelve weeks

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